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FIDELITY PHILADELPHIA

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 249 JANUARY, 1950 No. 1

THE FRANKLIN INSTITUTE FROM 1824 TO 1949

BY

THOMAS COULSON[1]

I. THE FIRST HUNDRED YEARS

An institution which bears upon the lintel of its main entrance the legend "In Honor of Benjamin Franklin" must display a diversity of interest and achieve a measure of popular acclaim before it can be judged worthy as a memorial of the great man whose name it bears. It must be truly American in spirit and performance. A resumé of The Franklin Institute's one hundred and twenty-five years of operation will prove that it has amply justified its claim to perpetuate the ideals of Franklin. For it has been a period of unbroken service to the community, and its splendid home in the heart of Philadelphia, Franklin's chosen city, is a monument to the appreciation and the generosity of the community benefitted.

In the first quarter of the nineteenth century, when The Franklin Institute was founded, the population of the city of Philadelphia did not exceed 65,000 and the number of inhabitants in the entire county was under 150,000. The nation was in the throes of great change. The industrial revolution was just taking shape. The people were learning that the transition from tools to machines was not simply a mechanical complexity. Popular opinion, molded by an economy based upon agriculture, was divided upon the desirability of manufactures. This attitude of mind was hindering the progress of the social adjustments which must accompany industrial growth.

Although the free school system had recently been adopted there were as yet no technical colleges, no vocational schools, nor any high school. The Mechanics Institute was the sole dispenser of technical education, and this was accessible only to those who had been apprenticed to a trade. The city was not devoid of learned societies, but

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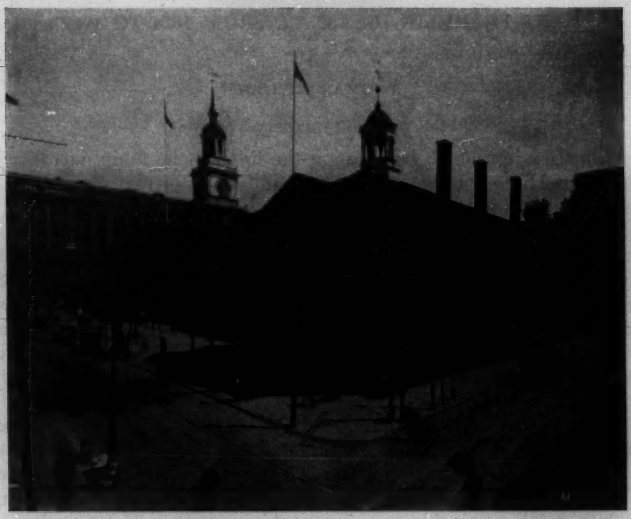
(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

membership in these was restricted and the members largely ignored the practical application of the sciences they discussed.

This deficiency in the educational facilities was brought home vividly to an ambitious young man, Samuel Vaughan Merrick, who had been given the opportunity to enter a small manufacturing business. Desiring to obtain the mechanical training required for the successful management of his business, Merrick cast about for instruction. To his dismay he learned that no means existed unless he became indentured to someone already established in business. He thereon resolved upon remedying this unsatisfactory situation. His purpose was to create



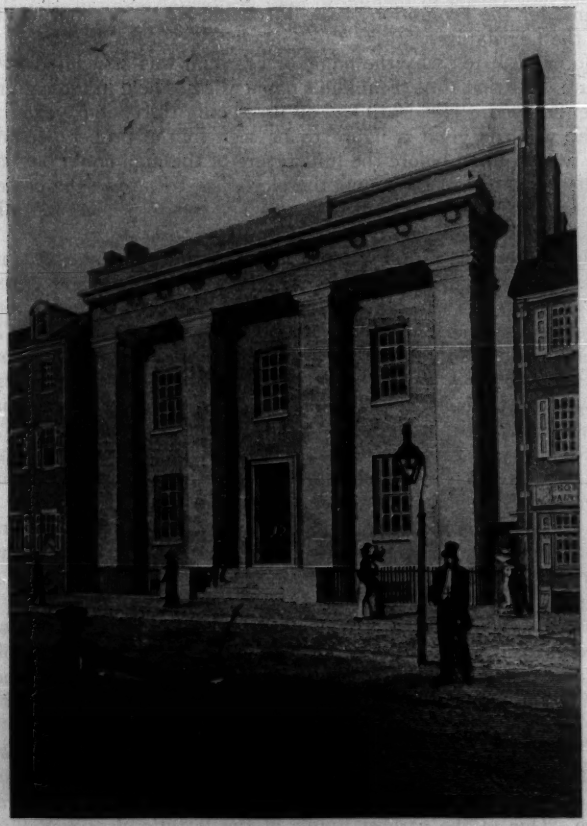
The County Court House

Where the plans for the foundation of The Franklin Institute were approved at a meeting held February 5th 1824

an institution where anyone, rich or poor, young or old could obtain instruction in the mechanic arts and allied subjects.

As with most pioneer enterprises, success was not achieved without a preliminary failure, but Merrick was not deterred by initial rebuffs. Eventually, he enlisted the sympathy of Dr. William H. Keating, professor of chemistry at the University of Pennsylvania, who shared his youth and his enthusiasm. Together they sought the support of a group of prominent citizens who met on December 9, 1823, in the hall of the American Philosophical Society. After hearing Merrick and Keating plead their cause the group agreed upon the need for an organi-

zation such as they proposed, and they decided the best means of gaining the necessary support for the realization of the idea was to address personal invitations to some twelve hundred persons to attend a meeting at which a provisional constitution would be presented.



The Institute's First Home

Erected in 1825 and occupied until 1934

This meeting was held on February 5, 1824, in the County Court House. Somewhat unexpectedly, the accommodation of the room was overtaxed by the attendance of professional men, manufacturers, and artisans. After the general purpose of the projected society had been

explained and the proposed constitution had been submitted to discussion, it was unanimously agreed to proceed with the organization of the society, and between four and five hundred of those present announced their readiness to become subscribing members.

On March 30, 1824, "The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts" received its charter from the Legislature.

No one can tell why the name of Franklin was associated with the venture. At that time, Franklin's name was not held in the high repute it later enjoyed. His death had occurred only thirty-four years before, and he was too great a figure to be seen in the proper perspective. Time was required before the full stature of the man could be realized. The happy choice of the name, therefore, is a tribute to the perception of the men who founded the Institute which was to perpetuate uniquely Franklin's gospel of service and pragmatism.

The first president was James Ronaldson, a prominent textile manufacturer and philanthropist. Among the original members were such men as Matthias Baldwin, Alexander Dallas Bache, Clement C. Biddle, Moses Brown, Mathew Carey, Frederick Fraley, Thomas Gilpin, Frederick Graaf, Adam Ramage, James Rush, and Thomas Scattergood. These men were among the foremost figures in the city life, but membership was thrown open to everyone, regardless of station or occupation. Among the first twenty names of applicants for membership were those of men who gave their occupations as fire engine maker (that was Merrick), merchant, brewer, teacher, plasterer, saddler, plumber, marble mason, clothier, shot maker, counsellor-at-law, and blacksmith. The great diversity of occupations reflected in the original members has been characteristic of the membership during the whole of the Institute's existence.

The enthusiastic founders were so determined to serve the community that their haste to do good was almost unseemly. Classes were started in April, 1824, with the appointment of Dr. Keating as professor of mineralogy and chemistry. These classes were held in the old Academy building on Fourth Street near Arch, which was owned by the University of Pennsylvania.

In October of the same year, Robert M. Patterson (later superintendent of the United States Mint) was appointed professor of natural philosophy and mechanics, and William Strickland professor of architecture. One of the earliest pupils of the latter's class was a young bricklayer, Thomas U. Walter, who so profitted from the instruction he received that he became conspicuous as the architect of Girard College, the United States Bank Building, and at the Capitol in Washington.

The School of Drawing opened at the same time, and the instruction offered was soon supplemented by courses in machine design, naval architecture, and mathematics. The lectures given to these classes

were designed to be useful to the students, but the general needs of the members were not disregarded.

American science, both pure and applied, was still drawing its inspiration from Europe, so that the first lectures to members were concerned with reports on the progress of science and technology and, as native techniques developed, men prominent in science and industry were invited to address the members. Thus was launched a series of lectures which constitute a valuable record of scientific and technical progress during that century when man made greater advances than in any similar period of his existence.

Some of the most eminent men in science, inventors, and leaders of industry have lectured before the members. In keeping with the ideal

Lecture Hall in the old building

of the founders, whose desire was to familiarize the members with latest information relating to their interests, the lecturers have frequently publicized ideas for the first time in this country. Professor Elihu Thomson gave a notable series of lectures on electricity in the fall of 1876, during which he made the observation of a phenomenon he later converted into the first practical method of effecting welding by means of electric current. In 1885, a member, W. N. Jennings, showed the first successful photographs of lightning in the lecture hall. Emile Berliner demonstrated the talking machine which employed the now familiar flat disc recording. In 1888, a workable voting machine was demonstrated, and an automatic telephone system was installed in the lecture hall in 1901. In 1916, the members were given the first

public demonstration of transcontinental telephony. These instances, selected more or less at random, illustrate the wide variety as well as the significance of the subjects treated by the lecturers.

Two outstanding series of lectures on basic science were given by Dr. F. W. Aston on "Atomic Weights and Isotopes" in 1922, and by Sir J. J. Thomson on "The Electron in Chemistry" in 1923. These lectures by distinguished Cambridge professors attracted a world-wide attention when published in book form, and the choice of their subjects serves to emphasize the alertness of the Secretaries to secure appropriate authorities who could present subjects which, subsequently, were to attain much greater significance.

The specific educational facilities provided at the beginning of the Institute's activities displayed a concern for the youth of the times, but the more mature elements of the community were afforded encouragement and aid in another form. The first quarterly report of the Board of Managers (April 5, 1824) contains a significant passage which is pertinent:

> It is confidently believed that when the products of our industry are collected from the various workshops now dispersed through the city and state, and exhibited together, they will form a collection calculated to excite a gratifying sense of pride . . . and an encouraging hope that under proper regulations we may compete with foreigners in the manufacture of all useful articles.

In these words the Board of Managers was giving expression to a wish which was latent in the comparatively inarticulate manufacturing community. One hundred and twenty-five years ago neither the manufacturers nor the consumers had any conception of the effects of the changes in impending living conditions involved in the development of processes, methods, and machines. There was no vehicle by which the consumer could learn how the manufacturer was striving to satisfy his needs, nor by which the producer could inform prospective customers of his accomplishment toward that end. Advertising had not found its voice.

The Franklin Institute, vitally concerned with the development of the sciences and their practical applications, accepted the responsibility for acting as the medium whereby the inventor, the manufacturer, and the consumer could be educated in the functions and relations which bound them in the pursuit of a common object—the conditioning of national industry to the needs of the nation. The implication of national production upon daily life was a matter of primary concern, but no agency had taken steps toward regulating it until The Franklin Institute voluntarily stepped into the breach.

In casting about for suitable means of drawing inventor, manufacturer and consumer together in closer relationship, the Board of Managers hit upon the happy idea of inaugurating trade exhibitions.

They proclaimed their intention of organizing the first such exhibition to be held in this country, and offered premiums for meritorious examples of certain manufactures. The sincerity and wisdom of the intention was reflected in the zeal with which the proposal was carried out. First suggested in April, 1824, the exhibition was realized the following October. Three hundred exhibits were accepted for display in the hall of the Carpenters' Company for a period of three days. They formed a strange assortment of goods from Maine, Massachusetts, Rhode Island, New York, Maryland, and Ohio, as well as from Philadelphia and the neighborhood. Ten silver and two bronze medals were awarded for such diverse products as blister steel and grass bonnets, japanned goods and broadcloths, bar iron and carpets.

The first exhibition was declared to be such an unqualified success that it was resolved to repeat it each year thereafter. Two purposes would be served by these exhibitions. They would stimulate interest and lead to efforts to improve upon what had already been accomplished, and they would show to those inclined toward invention what was the state of the practice in each particular field. The exhibitions were held annually until 1858, and had so grown in extent that the State Armory Building had to be engaged to provide space for all the exhibits. A notable feature of the last annual exhibition was the publication of a pamphlet describing the sewing machines exhibited.

After 1858, these exhibitions were held at irregular intervals, not because the Institute members were losing sight of their purpose, but because certain individual industries had matured and had gained the strength to stand upon their own feet. Specialized exhibitions had become necessary in order to display the rich assortment of goods pouring from the nation's workshops.

The popularity of the classes and lectures, and the prestige brought by the first industrial exhibition convinced the public that The Franklin Institute had a claim upon their support. The numbers of members increased rapidly. But its work and influence would have been localized had its activities been restricted to those provided by the primary organization. The need was expressed for a periodical publication which would extend the field of service. In addition, technical journals were expensive and inaccessible, and a need existed for one which could be placed in the hands of members at a reasonable cost. Accordingly, in August, 1825, a prospectus was issued announcing the forthcoming publication of THE FRANKLIN JOURNAL AND MECHANICS' MAGAZINE, under the editorship of Dr. Thomas P. Jones, professor of mechanics at the Institute. The purpose was proclaimed to be "to diffuse information on every subject connected with the useful arts."

Most of the early articles contributed were extracts or translations of interesting material published elsewhere, but the publication of original work was soon commenced and became the distinguishing feature of

the JOURNAL. The standard set for describing original work or the extension of that work has been held at a uniformly high level, so that THE JOURNAL OF THE FRANKLIN INSTITUTE (as it has been called since 1828) ranks among the leading journals devoted to science and technology. An unique feature of the early issues was the publication of abstracts of specifications and claims for patents which makes the JOURNAL the only source available for such information relating to the patents issued between 1828 and 1843.

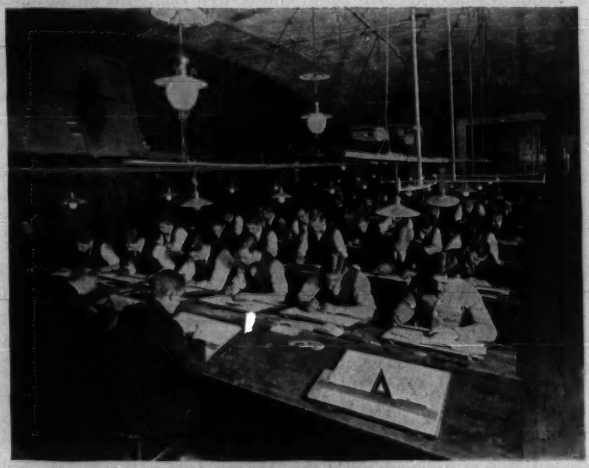
While all these activities had been engaging the attention of the members, steps were being taken to provide a permanent home in which all the varied activities could be concentrated. In common with most other organizations which came to life in the city at that time, the Institute meetings were held either in Carpenters' Hall or the Masonic Temple, on Chestnut Street above Seventh. Classes were still held in the Academy building, and the nucleus of the library was housed in the private residence of a member. In order that the Institute might have a headquarters, a plot of ground was purchased on the East side of Seventh Street, between Market and Chestnut Streets. The cornerstone of the building was laid on June 3, 1825. The architect was John Haviland, a member of the Board of Managers, and the building he erected served as the Institute's headquarters until the manifold activities caused a congestion that made removal a necessity a century later. The last meeting of the membership took place in the old lecture hall on November 3, 1933. Most appropriately, the familiar old building in which no small amount of local history was made, has been converted into a museum of Philadelphia history.

The provision of a permanent home permitted the Board of Managers to carry out a project which seemed desirable to complete their educational program. This was the establishment of The Franklin Institute High School for those earnest young students who found the instruction furnished by the free school system inadequate for their needs, but who were not yet capable of benefitting from the more advanced Institute lectures. To afford aspiring apprentices the occasion for improving their knowledge, additional classes of the Franklin High School were held in the evenings. In addition to instruction in elementary science and mechanics, the curriculum included geography, history, Latin, Greek, French, Spanish, and German. Under the capable and versatile Walter Rogers Johnson, the school attained an immediate success. In the first year after its inauguration, some three hundred students were enrolled.

The Franklin Institute High School was recognized as one of the most progressive of its kind and became the model for the first city high school when the local authorities assumed responsibility for providing the higher grades of education. As the more liberal studies began to receive more adequate treatment in the public schools, The

Franklin Institute's classes dealing with them were abandoned, and those which were retained were confined to scientific and advanced technical studies. It is noteworthy, however, that the school of mechanical drawing was continued for ninety-nine years. At the outbreak of World War II, a number of draughtsmen on changing their positions named the Institute's school as the place where they had received their training, and the records could be checked to verify their claims.

Although some subjects were dropped from the curriculum of the classes, the Institute did not fail to re-assume its pioneer role when new subjects justified. One of the first stenographic schools in the city was opened by the Institute in 1876 when Pitman's system of shorthand began to attract attention. Later in the century, special classes were



Drawing School

A class in session about 1907

opened in machine design and naval architecture, subjects neglected by other schools. On the entry of the United States into the first World War in 1917, a school of navigation for the United States Shipping Board was opened, and a free school for instruction in the newly discovered wireless telegraphy was made available for men subject to the selective draft.

Many hundreds of young artisans were greatly aided in their education, practical and theoretical, by the schools established by the Institute, and many men who distinguished themselves in various fields of activity have paid tribute to the worth of the instruction they had received in these classes.

An activity which, at first glance, looks to be beyond the range of the Institute's interests, was the formation in 1850 of the School of Design for Women. This was the outgrowth of a private school which had been opened by Mrs. William Peter. It was realized that The Franklin Institute, with its experience of schools and its associations with industry was ideally situated to promote the plan of training girls to make designs which could be applied to industrial products. A committee of management was appointed, rooms rented at No. 70 Walnut Street, and classes were started in elementary drawing and coloring, industrial art, wood engraving, and lithography. The classes were promptly filled with students, and the friendly relations existing between the Institute and industries were of aid in securing a market for the students' work. In 1853, the school received an independent

Reading Room

From a photograph taken about 1880

charter and, later, merged with the Moore Institute of Art, Science, and Design.

A partial reason for establishing the JOURNAL was to supplement the purpose of the library in making available more numerous scientific and technical journals. By arranging for a judicious exchange with other periodicals, the Institute, as publisher of its high standard JOURNAL, was enabled to obtain a regular supply of domestic and foreign periodicals for the use of members. With the provision of a permanent home, it became possible to extend the reading facilities. In addition to storage space for the books, a reading room was furnished in the new building. The publications and periodicals of other learned societies had all been carefully preserved and this had permitted the accumulation of an invaluable collection of complete "runs," which constitute a priceless tool for the research student.

One of the problems uppermost in the minds of the founders was the need for a competent and trustworthy group of men upon whom scientific investigators and inventors could rely for an impartial judgment upon the merit of their work. In 1824 a board of examiners was appointed to undertake the work of scrutinizing all claims submitted to them. In 1834, the name of this board was changed to that of the Committee on Science and the Arts. In those early days this Committee gave counsel, based upon the wide experience of its members, to would-be inventors by informing them upon what had already been accomplished in their fields so that they might be spared the waste of time in duplicating the work of others; and when an idea of real originality or value was submitted to their consideration, they gave it an endorsement which would commend it to the public.

It should not be forgotten that the slow movement of agriculture was just then being interrupted by a quicker tempo. Invention had become the vogue; it was soon to change into a swelling tide, an impulse in itself running ahead of necessity. One feels that the founders, with sure vision, had made provision for this tide of ideas which was to sweep forward the nation's industry. In the work of the Committee on Science and the Arts one also perceives a reflection of the trust placed in the Institute by the innovators of the times. During the first eight years of its operation (1825–1833) one hundred and one applications for investigation were placed in the hands of the Committee.

As the usefulness of The Franklin Institute in this direction was recognized and the impartiality of its judgments was appraised, it became the custodian of several funds for furnishing medals which were to be awarded to those who advanced ideas for scientific applications contributing to the welfare of mankind. The awards of these medals are made upon the recommendation of the Committee on Science and the Arts.

Reference has been made to the Institute's services to the community without allusion to specific instances. Since this constitutes an unique record of achievement, space must be found to mention the principal accomplishments.

At first the investigations were undertaken upon the initiative of the members but, as their value became apparent, the city, State, and Federal authorities brought problems for solution. It may seem strange that so many of the functions of public departments were farmed out to this body of enthusiastic investigators and it provides an interesting commentary upon the national organization of the time that the members of the Institute were the only organized body qualified to perform these functions. However, before the public authorities came to the Institute for aid, the various committees of inquiry had independently proved their worth.

Two designs for dry docks had been submitted through the usual

channels for examination, but the subject was a matter of such importance that the Institute decided to extend its inquiry to the whole field of the dry dock situation. Existing provisions in this country were so inadequate that shipowners were frequently compelled to send their vessels to Europe when major repairs were necessary. The committee appointed, therefore, made a thorough investigation into the whole subject. Their report, published in the JOURNAL, was a comprehensive survey of the situation. This made recommendations, with estimates of cost, which would be of material assistance to those who undertook to remedy the defective situation, and did not omit to give appropriate consideration to the two designs which had provoked the investigation.

Since this inquiry pointed the way in which the Institute could be of marked service to the community, it was speedily followed by another committee which was assigned the task of investigating the principal source of industrial power. Steam engines had been accepted in marine and railroad development but they had only a limited application in stationary form. The principal source of power remained the waterwheel. This useful machine was of paramount importance since it drove all forms of mill, and mills were rarely idle unless their streams were frozen. As seasonal requirements dictated, these could be adjusted so that a grist mill could become a sawmill, a flax brake, or a fulling mill; when not grinding corn, a mill could grind rags for paper, malt, plaster, mustard or tobacco. The proposed inquiry, therefore, was of wide economical interest.

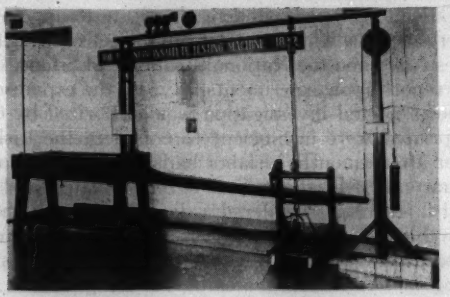
Most waterwheels were of the breast-wheel type, where water was admitted to buckets near the top and rejected near the bottom of the wheel. Although of very ancient origin the waterwheel had received very little attention and had undergone only slight improvement. The Institute's investigation resulted in the assembly of an amount of data not generally available to the constructors of wheels, and as iron was then being freely introduced enabling larger waterwheels to be made, these data permitted a higher degree of efficiency to be attained.

The initial report was so favorably received that the investigating committee was encouraged to extend its study to overshot and undershot wheels. Altogether over seven hundred experiments were performed with waterwheels of various descriptions, and the reports were of the greatest value to those who were constrained to use water as the source of power. Even when steam power was making rapid inroads into industry, the members of the Institute perceived the possibilities inherent in improved water power and they made an investigation into the Fourneyron water turbine, a waterwheel with a vertical axis, which could successfully compete with steam in certain circumstances.

However, the advances of steam power could not be denied but, for a period, it seemed that the frequent boiler explosions which occurred,

notably on steamboats when high pressure steam was employed, might retard the progress of this form of power. Since the confidence of the public was shaken by the frequency of these explosions, often accompanied by loss of life, the members of the Institute decided to open an inquiry into the causes of the explosions. This investigating committee was appointed in 1830.

The work of the committee soon began to attract attention and among those interested were government officials who were disquieted by the frequency of the explosions. As an outcome of their concern, Congress appropriated funds to permit an inquiry into the situation. A portion of the funds was offered to The Franklin Institute committee to make a more thorough investigation than they had planned. The sum awarded to the Institute was devoted to an examination of the strength of materials employed in boiler construction. At first, the



First Testing Machine

The first machine for testing the strength of materials was the outcome of an Institute investigation

experiments were conducted at considerable personal risk to the investigators since the only way of ascertaining what pressure a boiler would stand was to raise the pressure to bursting point. The test-house on Vine Street which was used as a laboratory, did not add to the amenities of the neighborhood.

Another interesting feature of this report is the account of the first scientific investigation of rivetted joints. The investigators discovered that the joints were stronger than the sum of the shear strengths of the rivets, and they correctly ascribed this to the friction between the plates.

Apart from the valuable analytic studies performed, the work of the committee on steam boilers produced another noteworthy result in the design and construction of an apparatus for testing the strength of materials used in boiler construction. This machine, still preserved in the Institute's Museum, marks the beginning of the science of testing the strength of materials in systematic manner.

One other feature of this investigation which should not escape comment was the participation of the government. This marks the occasion when the Federal authorities first appropriated funds for the conduct of scientific research. The money granted by the authorities was used solely to defray the costs of the experiments, and none was diverted as recompense for those who carried out the work. Such work would now be performed by the National Bureau of Standards, established in 1901, and it will occasion no surprise to state that the Bureau was created largely through the advocacy of the members of The Franklin Institute.

The Institute committee published a number of reports in the JOURNAL which attracted such widespread attention among engineers that when the work had been completed only a short time elapsed before pressure was brought to bear upon the Institute to appoint another committee to carry on the labors. Later still, in 1864, the Secretary of the Navy (Gideon Welles) invited the Institute to appoint three members who were to serve with a similar number of representatives of the United States Navy and the National Academy of Sciences "to conduct, witness, and report upon experiments . . . on the expansion of steam." Although the projected investigation was authorized by Congress, the funds appropriated were insufficient to complete the task, which terminated after fifteen months of labor had been devoted to it.

On February 24, 1844, the U. S. S. *Princeton*, latest and most heavily armed vessel in the Navy, suffered a disaster through the bursting of one of her twelve-inch guns, the largest in the world. President Tyler who was aboard providentially escaped but the secretaries of State and the Navy, together with several members of Congress and the gun crew were among those killed. The Franklin Institute appointed a committee of its members to investigate the cause of the explosion. One of the members was Joseph Henry, the greatest living American scientist. When an iron bar similar to that from which the gun had been cast was submitted to breaking tests, it was observed that it ruptured with a cup-shaped fracture. This led to the conclusion that molecular cohesion within the interior of the metal was not as strong as that near the surface, a scientific fact hitherto unobserved.

The study of the weather is always a matter of importance to a community largely dependent upon the sea and the soil for its support. It is only natural, therefore, to find the Institute early taking an active part in the study of meteorology. The State Legislature appropriated funds for the purchase of equipment and the Institute produced some of the ablest meteorologists of the time from among its members. Even when the State grant ceased and the co-operating bodies had withdrawn from the work, the Institute continued its researches into the weather. Later, when the Signal Corps of the United States Army took over the direction of systematic weather observations in 1870, a

State Weather service was inaugurated by The Franklin Institute's voluntary workers with state aid for the purchase of uniform equipment. This service remained in operation until 1891 when the Legislature's appropriation was discontinued.

Members of the Institute continued to display interest in meteorology. This interest was demonstrated in signal manner when Dr. W. J. Humphreys, of the United States Weather Bureau, selected the JOURNAL as the medium for the publication of a series of articles on the subject. On completion of the series, the articles were revised by the author and published in book form by the Institute under the title of *The Physics of the Air*. The volume was promptly accepted as a standard work in its field.

The Institute continues to this day to display its interest in meteorology, for it is one of the reporting stations of the national Weather Bureau.

In continuation of the account of the research undertaken for the Federal authorities, mention must be made of the important step taken by the Institute to secure the standardization of screw threads and nuts. Today, when we enjoy the use of so many standard articles for interchangeable use, it is difficult to picture the confusion, expense, and exasperation experienced by employers and artisans when each shop had its own ratios and forms of threads. The agitation for simplification was initiated by members of The Franklin Institute and a practical scheme was outlined by the president, William Sellers, in a paper read before the members and their friends on April 21, 1864. The reform advocated was so obviously required that it was adopted by the United States government in 1868 under the name of The Franklin Institute or the Sellers system of standards. The Pennsylvania Railroad ordered a set of gauges for the new sizes in 1872, and the Master Car Builders Association recommended that the system be adopted as standard on all American railroads. Thereafter it quickly came into general use.

The Commonwealth of Pennsylvania has on occasion turned to the Institute for aid in the solution of its problems. In 1833, a bill was presented to the Legislature relating to the weights and measures of the State. As this involved some highly technical matters, beyond the capacity of the legislators, it was referred to the Institute membership with a request for study and recommendations. A special committee was appointed and the customary painstaking investigation was made into the subject, including the systems of weights and measures used in European countries. The present laws of the State are based upon the recommendations of this committee, and the standard units were constructed under the supervision of its members.

An unofficial geological survey of the resources of the State of Pennsylvania was begun in 1832 which led to the inauguration, two years later, of the first official survey of this nature, in which several

members of the Institute participated. In 1873, when new mineral substances were finding applications, the Institute promoted the Second Geological Survey, for which the legislature voted the necessary funds in the following year.

Having at hand this competent group of investigators, it was convenient for the city authorities to turn to them for expert advice. In 1843, at the request of the City Councils, an investigation was made into the best method of paving the streets of Philadelphia. After a careful study had been made of the soils and drainage, and the relative merits of asphalt, wood, and stone pavements had been investigated, recommendations were made for paving the city streets. Plans and specifications were provided and the manner of superintending and executing the work was described.

After performing several minor services for the city authorities' benefit, the Institute was invited to appoint a commission of five scientists and practical engineers to investigate the pumping stations and reservoirs upon which the city depended for its water supply in the year 1873. The investigation undertaken embraced all the existing facilities and went on to indicate the sources from which future needs could be met. Seven years later another commission of engineers, selected from a panel recommended by the Institute, was appointed to study the future needs of the rapidly expanding city, and to make recommendations to prevent the waste of water. The report of this commission was published in the JOURNAL (as were other reports or abstracts of investigations undertaken by the personnel of the Institute) and forms an eloquent statement of the best current practice in pumping machinery, the location and construction of reservoirs, and the management of stations.

A striking feature of the report is the recommendation of the installation of meters to measure the volume of water consumed by individual factories and large buildings, so that the main consumers of water might be charged an appropriate share of the cost of water supply.

Solicitude for the public health is reflected in the investigations made into the pollution of the Schuylkill River and into the smoke nuisance, now that smokestacks had become a familiar feature of the city landscape.

The appearance of light petroleum oils as illuminants led the Institute in 1873 to enter upon an examination of their suitability for domestic use, and to investigate the cause and prevention of fires originating from the use of these oils, which were replacing whale oil. The report upon this subject is a model of its kind. It made recommendations for the restriction of the sale of certain types of oil, specified the characteristics of safe oils, and aided in clarifying a situation which threatened to become a menace to the health and safety of the families who continued to use oil lamps.

The first electric dynamo tests ever made were conducted by an Institute committee in 1877. Professors Elihu Thomson and Edwin J. Houston performed the electrical measurements involved, designing the means since none had previously been described. The final report of this committee is a classic of simplicity and directness. It became the standard procedure for such tests.

The investigations of fire hazards begun ten years earlier were carried to a brilliant conclusion in 1883 when a committee was appointed to study the hazards of artificial lighting, heating apparatus, the use of fireworks, and spontaneous combustion, especially in regard to their causes of fires in theaters and public buildings. After a most comprehensive investigation of several conflagrations which had served to focus attention on the subject, the committee issued a report which concluded with thirty-eight recommendations. These are nearly all now universally embodied in the building codes covering theaters and public halls, although at the time they were framed they bore the imprint of revolutionary novelty. They included the installation of fireproof curtains, fixed seats, exit doors opening outwards into the street, the introduction of panic bolts on exit doors, and the regulation of aisle spaces.

Thus it will be seen that the members of The Franklin Institute had been actively employed in making a growing city cleaner, healthier, and safer. Meanwhile, it occasionally turned aside from mundane problems to promote the advance of pure science, as when it equipped and sent out parties to observe solar eclipses.

The Institute had pioneered in several movements only to withdraw when more appropriate sponsors assumed responsibility. But it was always ready to re-assume the role of pioneer when the occasion demanded. In the year 1869, The Franklin Institute took one of the most influential steps in its history, important not only because of the comprehensiveness of the plan but as regards its conduct to a successful termination. A committee of three members was designated to present to Congress a memorial recommending the centennial celebration of American independence by an international industrial exhibition. When this was sympathetically received, a more comprehensive committee composed of representatives of the Legislature, the City Council, and the Institute was formed to further the proposal. The recommendations of this group induced Congress to pass an Act giving official sanction for the holding of an "International Exhibition of Arts, Manufactures, and Products of the Soil and Mines," to be held in Philadelphia during 1876.

Meanwhile The Franklin Institute had held an exhibition of its own to celebrate the fiftieth anniversary of its founding, which fell in 1874. This exhibition was in the manner of those pioneered earlier and held annually until 1858. Apart from a wish to reproduce an old practice

which would reveal the progress made by the nation's manufacturers, the Institute had the praiseworthy intention of reestablishing among manufacturers their habit of using Philadelphia for displaying their products. The exhibition was an unqualified success for it attracted over 1200 exhibitors and 268,000 spectators. Its most notable contribution to the joy of living was the introduction of the ice cream soda, which was first put on sale here.

This anniversary exhibition also served as a rehearsal for the great Centennial Exhibition which was held in 1876. This was the first international exhibition to be held on this continent and it served the dual purpose of marking the completion of a century of independence and demonstrating the great progress made by industry during that period. In those days American visitors to Europe were not as numerous as they are in our day, communication was neither as safe nor as comfortable, so that the bringing of products from all parts of the world to our door enabled many thousands of people within easy travelling distance to see these and to receive inspiration for the improvement in their own work, theoretical and practical.

The benefits to be derived from exhibitions of this nature are often of an intangible nature that is difficult to measure, but the influence of the Centennial Exhibition upon American culture was positive. The joy of seeing strange things from distant lands was combined with the pride aroused by the comparison of American-made things with those produced by other peoples. Never before had the American people had the opportunity to see such an assembly of exhibits representing the arts and sciences as practiced by man in different climes and under various forms of government.

But, while the general public was still rejoicing in the display of power revealed by this exhibition, the Institute members were already at work planning another exhibition. They had perceived a new force on the industrial horizon. In order that the nation might be made aware of the many useful applications of electricity and its vast potentialities, the Institute organized in 1884, without outside aid, the first Electrical Exhibition. The exhibits were international in scope and sufficiently numerous to require a large exhibition space. This was found in the Pennsylvania Railroad freight station at Thirty-second and Market Streets, and in a special building adjoining. Although the electrical industry was in its infancy this exhibition was supported by 216 exhibitors.

This exhibition had likewise far-reaching results. The United States Electrical Commission was established by Act of Congress and invitations were issued to a large number of scientists, American and foreign, who were in conference during the six days the exhibition was open to the public. From this conference emerged the most complete and extensive series of tests in electrical apparatus and appliances that had been made.

The American Institute of Electrical Engineers also came into existence as a result of this exhibition.

In the following year the same buildings were utilized for an exhibition of novelties of American manufacture in which 375 manufacturers contributed their products for display. In co-operation with the Commercial Museum of Philadelphia, The Franklin Institute then organized the National Export Exhibition in 1899. This closed the long list of special exhibitions which the Institute had inaugurated seventy-five years earlier.

Otherwise, the Institute continued its functions, modifying them only to keep abreast of the changing times. The list of distinguished scientists and industrial workers singled out for recognition grew more

First Franklin Medallist

The first Franklin Medal was awarded to Thomas Alva Edison

and more impressive. The Franklin Medal, instituted in 1915, is the highest award the Institute has to offer, and the first award to Thomas Alva Edison signified the standard of achievement it was to recognize. In the following years such intellectual giants as Arrhenius, Dewar, Einstein, Lorenz, Marconi, Rutherford, Thomson, and Zeeman, to name only a few, were among the recipients.

As we have observed, The Franklin Institute had been keenly interested in research from the time of its inception. This had been undertaken sporadically as occasion required by groups of the members. High hopes of establishing "an experimental workshop" had been entertained by the founders but had never been realized for lack of funds. The greatest credit is due to those who had conducted the investigations

without recompense. We have seen in this account of their accomplishments that much work of an invaluable nature had been performed, but it was always hoped that research of a fundamental nature might be undertaken. The Institute had never lacked for men of vision who could perceive what needed to be done and the best way to do it, but the necessary funds were wanting.

The realization of an ideal was achieved after almost a century of waiting. In 1918 Henry W. Bartol, a prominent Philadelphia industrialist, bequeathed his residual estate to The Franklin Institute for the establishment and maintenance of a laboratory for physical research. The bequest amounted to nearly one million dollars. After a very careful search for a suitable director, the choice of the Board of Managers fell upon Dr. W. F. G. Swann, of Yale University.

Active work began in 1925 in four vacated dwellings which the Institute owned at Nineteenth and Race Streets. The location of the laboratory at a busy city intersection proved a severe handicap in the use of sensitive instruments, so that a permanent home had to be found on a site which would be free from vibrations and other disturbing causes. This was located on the campus of Swarthmore College. Here the Bartol Research Foundation laboratories have conducted researches into fundamental problems of electricity, chiefly in the field of nuclear physics. In the pursuit of this object cosmic ray phenomena have been intensely investigated in various locations on the earth's surface and at altitudes extending into the stratosphere.

The realization of the wish to have a research laboratory proved to be more than the culmination of a century of progress devoted to science and industry. It turned out to be a signpost, pointing to a new order in which research would become a major factor of the Institute's activities.

II. THE NEW ORDER

The exercises attending The Franklin Institute's one hundredth anniversary were symbolic of the changed conditions of thought which prevailed after the conclusion of a world war. The nation had passed through a period of strain and stress, and was faced with new responsibilities. In taking an accounting of the position in which it found itself after a century of existence and face to face with a changed national outlook the program of the celebration placed less emphasis upon the past than it did upon the promise of the future. Since this was also the year in which the Bartol Research Laboratories were formally opened, the occasion was seized to accent the growing importance of science in everyday life. The three days of exercises brought together the most distinguished gathering of scientists that had assembled in America. The various sessions were devoted as far as possible to the presentation of the substance of scientific revelation and speculation of the time.

When the guests, seven hundred and fifty in number, had departed,

the members of the Institute took stock of the situation and decided that provision must be made for the future. For many years it had been apparent that the Institute had outgrown its home and that steps must be taken to find a more commodious edifice if the Institute was to retain the flexibility which would permit adjustments to be made to meet conditions where science was furnishing industry with more materials and processes than ever before. A committee had been formed in 1906 to prepare plans for a new building and to survey the means by which the requisite funds might be raised. This committee was instrumental in securing from the city of Philadelphia part of the accumulated fund left by Benjamin Franklin to be used for advancing loans to needy apprentices. The original bequest of $5000 had grown to a substantial figure, from which $125,000 was allotted to the Institute for the purpose of assisting in the erection of a new building.

In contemplating the provisions which had to be made in a new building, the specific requirements of the Institute had to be merged with those of the community in which it was situated. The population had grown to nearly two millions. The area had acquired an unusually diversified number of industries and housed a correspondingly large number of technical workers. Regard had to be given to the needs of those workers who were dependent for their living upon the thousands of industrial plants in the city, and for the students who were attracted by the many colleges and technical schools in the area.

The growth of the library had been phenomenal. From a shelf of books in a corner of a member's residence it had grown into one of the world's most complete specialist libraries. The remarkable reputation it enjoyed among experts and students was in large measure due to the wide knowledge and urbanity of the members of the staff. The library had been of inestimable value in the growth of ideas, in promoting discovery and invention, and in saving inventors much unnecessary trouble by informing them upon the state of their art. Several generous contributions of funds had assisted in the purchase of books. But the library was in urgent need of additional space, both for its books and its readers.

The growth of membership accounted for larger attendances at lectures and the needs of the lecturers called for technical facilities which could not be furnished in the old lecture hall.

These were activities whose growth could be measured in order to make provision for the future, but some other needs had to be anticipated when a new building was contemplated. An entirely new means had to be devised by which the Institute could encourage youths in scientific and technical studies, and the lay public in general might be kept informed upon the continual changes in technological methods. It was felt that in abandoning its schools the Institute had departed to some extent from the principles of the founders. The departure had

not been due to diminished interest but to want of opportunity. In order to meet entirely changed conditions in the educational field the Institute had to adopt new means of diffusing a knowledge of science and its developments as they affected the everyday life of the people.

In 1922 the Board of Managers conceived the idea of founding a technological museum upon a pattern which had been adopted in Europe but which had not been attempted on this continent. Such a museum would fulfill an unique role both as a supplement to the education of youth and as an agency for adult education. In 1925, Dr. Howard McClenahan, former dean of Princeton University, was appointed Secretary to the Institute, and he possessed those qualities of mind and personality required to deal with the problems confronting the Institute.

Breaking Ground

General view of the ceremony at ground breaking for the new building

He was an enthusiastic advocate of the idea of the technological museum. Unhappily the projected scheme called for the control of expenditures beyond the Institute's resources. Progress was slow until a happy solution to the financial difficulties was presented.

At the annual dinner of the Poor Richard Club in 1927, the proposal was made that a national memorial should be raised to Benjamin Franklin and that the most fitting location would be in Philadelphia. As a companion organization bearing Franklin's name and pursuing his vital purpose, The Franklin Institute was invited to take part in the meetings arranged to discuss the proposed memorial. It became clear at the outset that a suitable memorial to a man whose most distinctive

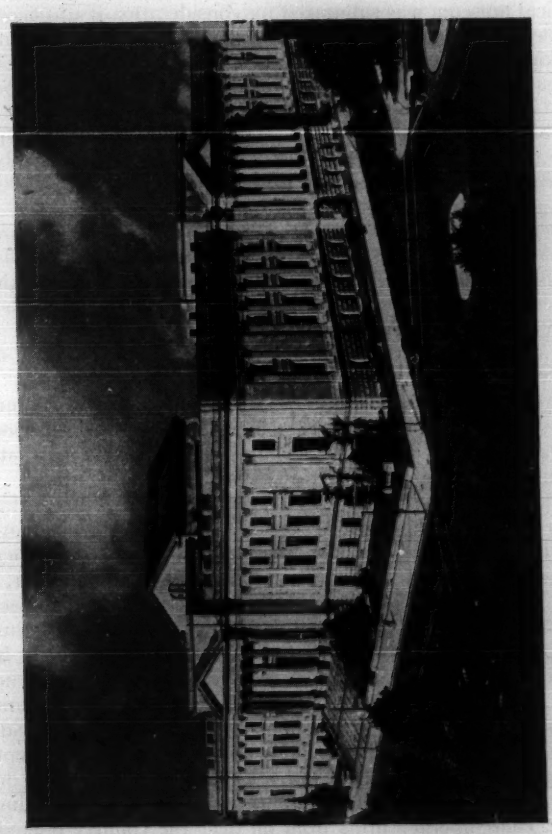
characteristic was a determination to be useful in whatever he did could not be fully served by a carved block of stone. It would have to be invested with a dynamism typical of the man it commemorated and it must serve the needs of the community. When the idea of a scientific and technical museum was submitted for consideration it was accepted as ideally designed to serve as a living memorial to the versatile Franklin.

A working agreement was arranged whereby the Poor Richard Club should organize the Benjamin Franklin Memorial Corporation for the purpose of raising the necessary funds, and The Franklin Institute should mobilize its resources to plan the erection, equipment, and operation of the memorial museum. Both organizations were admirably designed to carry out their respective tasks, and each produced a leader with the qualities for drawing the best out of their organizations.

The Benjamin Franklin Memorial Inc., achieved a phenomenal success under the leadership of Cyrus H. K. Curtis, the famous publisher, who was ably assisted by George Wharton Pepper and a group of prominent citizens gathered to serve on its Board of Directors. Although it was feared that the financial stringency which marked the year 1929 would paralyze their efforts, the redoubtable group resolved upon launching the campaign to raise funds in the following spring. The result fully justified their confidence. Nearly one thousand volunteers were enlisted in the task of soliciting funds. In the brief period of twelve days a sum exceeding $5,100,000 was pledged, Mr. Curtis setting a contagious example by the generosity of his own contribution.

Two other donations call for special mention. The proposed building plan provided for the construction of a large marble chamber designed to house the tangible memorial to Franklin. The generous contribution of William L. McLean, the local newspaper publisher, was earmarked for the provision of an heroic sized statue. The second notable donation was that of Samuel S. Fels, the well known industrialist and philanthropist, who had desired that Philadelphia might have a Planetarium. When the object of the memorial was made known to him, Mr. Fels offered to defray the cost of a Planetarium instrument and the special demonstration chamber it required if this would be incorporated in the new building. His offer was instantly accepted.

Nor was The Franklin Institute's prestige ineffective in securing other gifts. Mindful of the practical assistance it had rendered to industry in the past, contemporary firms from all over the country offered to furnish the museum with suitable exhibits. The city of Philadelphia granted a large plot of land at nominal rental for the site and, on his eightieth birthday, June 18, 1930, Mr. Curtis cut the first sod of earth to start the excavations. While the building was in progress, the arduous task of collecting, designing, and making the museum exhibits was being carried forward by a group of experts under the inspired leadership of Dr. McClenahan. Since it was proposed to allow the visitors



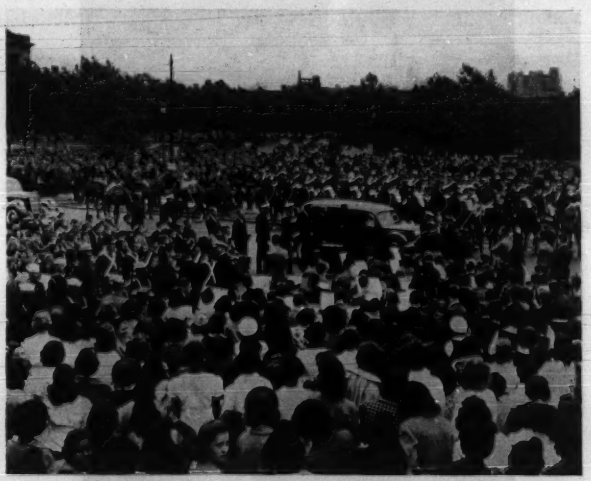
The Franklin Institute

The present home of the Institute on the Benjamin Franklin Parkway in Philadelphia

to operate the great majority of the exhibits, many problems of design had to be worked out, and the exhibits with historic value had to be adequately protected against injury.

It had been decided to construct only one half of the projected building, leaving its completion until a later date. The building as provided embraced The Franklin Institute's staff offices, the Franklin Memorial chamber, the library, the Museum, and the Fels Planetarium. The last was the first unit opened to the public, November 6, 1933, and the Museum was thrown open, January 1, 1934.

During all the fatiguing duty of directing the continuing activities of The Franklin Institute and organizing new ones, it seemed that Dr.



Dedication Ceremony

The arrival of His Excellency the French Ambassador

McClenahan's energies were inexhaustible. But when all was finished, his health declined and he was compelled to seek rest. In October, 1935, Dr. Henry Butler Allen relieved him of the duties of Director of the Museum and, on Dr. McClenahan's death in the following October, those of the Secretaryship.

This was a logical succession as Dr. Allen's experience had furnished him with a knowledge of the problems to be faced. He had been a member of the Committee on Science and the Arts from 1917, and had been the chairman of the Museum Committee since 1933. In another sense he was competent to serve as liaison between the Institute and industry. His training as a metallurgical engineer had obtained for him

influential positions from which he learned the attitude of industry toward the Institute. More recently, Dr. Allen's titles have been changed to Executive Vice-President and Secretary to meet a redistribution of duties. Upon him fell the task of organizing the next important celebration.

The culmination of the years of preparation was reached on May 19, 20, and 21, 1938, with the dedication of the Franklin Memorial. This had been delayed through pressure of work upon the sculptor, James Earle Fraser. At last the heroic sized statue was ready for unveiling

Benjamin Franklin

The heroic sized statue by James Earle Fraser

and three days of ceremonies were planned to make the occasion evident that Franklin's spirit was to be the living presence and inspiration in the national shrine erected to his honor.

The Institute had more than once organized some notable gatherings of front rank scientists, industrial leaders, and engineers, and this assembly was fully comparable to its predecessors. Practically all the leading institutions of learning and industry sent representatives, fifty-seven of whom came from foreign lands.

On the first morning of the ceremonies a branch post office was opened in the building with the sale of a new half-cent stamp bearing a

reproduction of the statue head. The first day sale of these stamps fell only short of one and a half millions. In further honor of Franklin as a postmaster an exhibit of American stamps was held to which the President of the United States, the Secretary of the Interior, and sixty other exhibitors contributed to make this the finest exhibition of its kind that had been held.

In the afternoon and in the presence of the French ambassador, Count Rene Doynel de Saint Quentin, the Secretary of Commerce representing the President of the United States, and many other distinguished visitors, the noble marble statue was unveiled. In tribute to Franklin's public services in other fields, the United States Army demonstrated the latest mechanized equipment to illustrate the applications of science to national defense, and the Navy Department docked two modern ships

A Distinguished Visitor

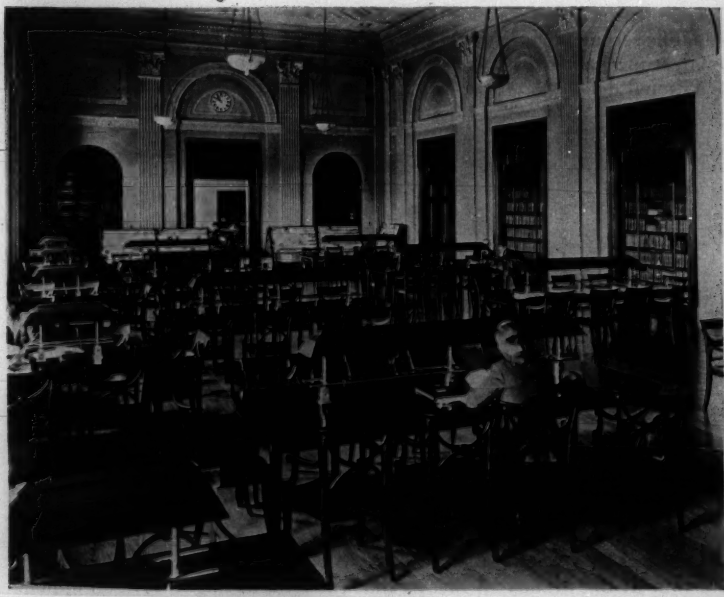
Among the many distinguished guests who have attended Institute functions was Mr. Herbert Hoover, former president of the United States

of war at the Municipal Pier so that the citizens might have an opportunity to inspect them.

The other two days of ceremonies were devoted to lectures and addresses by outstanding speakers dealing with Franklin's many interests. Not the least impressive of the many tributes paid to Franklin's memory was the demonstration given by thousands of youthful Philadelphians.

Now that the story of the achievement has been told, something must be said of the activities which are pursued in the building. Of the old activities of The Franklin Institute, the library, the lectures, the work of the Committee on Science and the Arts, little more need be said other than to mention that they have kept pace with the times in more appropriate surroundings. The library has grown enormously until it now comprises 130,000 volumes and 44,000 pamphlets. A

spacious reading room was provided for the comfort and convenience of members who use the library. This handsome room is called Pepper Hall in recognition of the services of George Wharton Pepper, former United States senator who had served as chairman for the fund raising campaign. The lectures are now given in a hall adapted to the purpose. Bearing in mind the requirements of lecturers who illustrate their talks with practical demonstrations, the modern lecture hall is fully equipped with laboratory and sound motion picture projection facilities. The



Pepper Hall

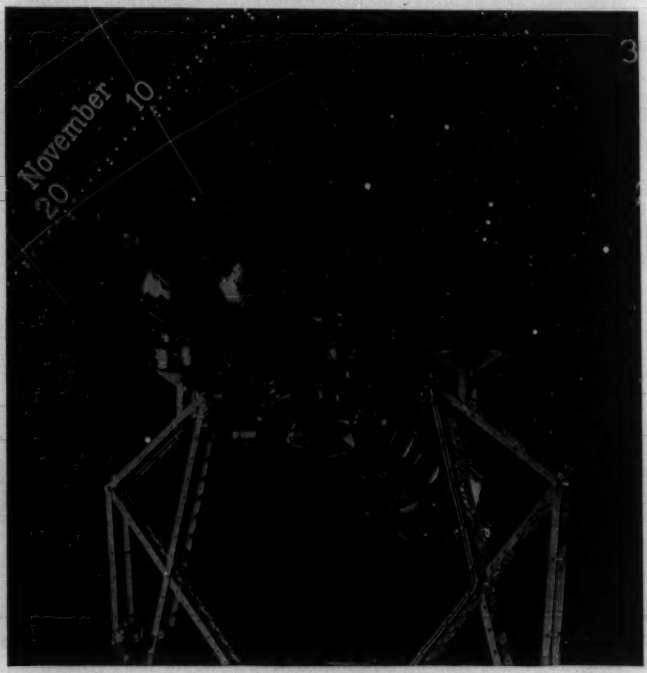
The Reading Room in the Library

acoustics are of a high order. Its attractive decoration and efficient equipment have made the lecture hall popular as a meeting place for other scientific societies.

The requirements of young people are not overlooked in the lecture program. Recognizing that science requires a simplified treatment in order to present it to untrained minds, a special series of lectures was established in 1926, and these were intended to have a special appeal to children. At the close of the series, Mrs. James M. Dodge founded the James Mapes Dodge Lecture Foundation in memory of her husband,

a well known industrialist who had been a long time member of the Institute. These lectures, given every Christmas week, are invariably accompanied by a large number of demonstrations and experiments, performed with readily obtainable materials, and are a most appropriate form of memorial to one who was himself a distinguished engineer and inventor.

For the first ten years the present building was open, the annual Medal Day ceremonies were held in the lecture hall. More recently,

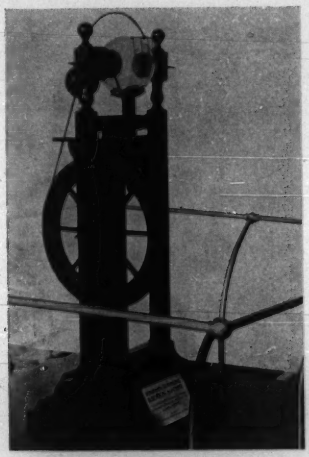


The Planetarium

This instrument reproduces the stars as they appear from any place on the earth, and at any time—past, present, or future.

these ceremonies have been held in the Franklin Hall which is commodious enough to be converted into a banqueting hall for this and similar occasions. Medal Day is now an important affair, since the Committee on Science and the Arts recommends recipients for thirteen awards. The Vermilye Medal has its special "day," since it is made the occasion for the delivery of an address upon a specialized topic.

But the features of the new building which are best known and have found the loudest expressions of approval are the Fels Planetarium and the Museum. The Planetarium has been the source of wonder and instruction to thousands of people who would otherwise have been unable to obtain a knowledge of astronomy. The ingenious instrument permits the demonstrator to project upon the domed ceiling an exact replica of the stars and planets as seen from any place on the earth's surface and at any time in the past or future. The movements of the planets and the apparent motion of the earth is also reproduced. By changing the subject of the demonstration almost every month it is possible to give during the course of a year a popular series of demonstrations covering



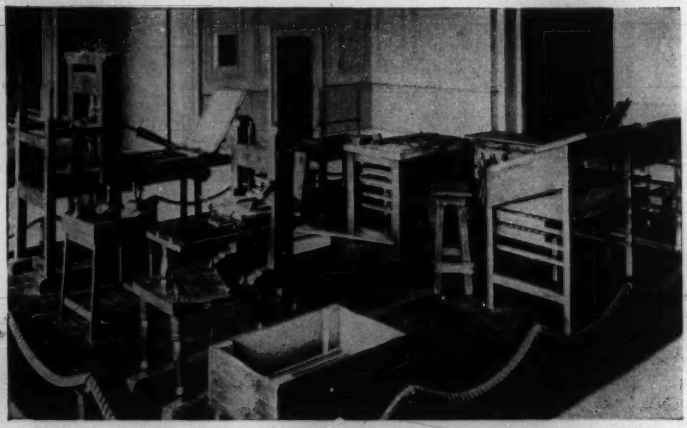
Franklin's Electrical Machine

With which some of his most important experiments were performed

the principal astronomical phenomena. Certain demonstrations are accompanied by highly spectacular stage effects which convert academic knowledge into entertaining and instructive talks for the layman. The Fels Planetarium has exercised such a strong fascination for young people that special demonstrations are arranged for them. Students from kindergarten to high school age have astronomy explained to them in language adapted to their understanding. Each Christmas a special demonstration with devotional and musical features treats with the "Star of Bethlehem" in which the skies as they appeared over Jerusalem at the time of the Nativity are shown.

The Museum introduced to America a new phase of visual education. Intended to center around the scientific interests of Benjamin Franklin

it furnishes a comprehensive survey of science and its numerous applications in everyday life. It is a virile dynamic assembly of exhibits, the antithesis of the old museums which are aptly described as "community attics." Through generous donations during its long history The Franklin Institute has become the custodian of some famous historical apparatus. That which was used by such famous men as Franklin, Faraday, Priestley must of necessity be preserved from the danger of injury, but everything else is freely placed at the visitor's disposal for actual use. Visitor participation is the keynote to the conception of this museum. It has been achieved through the construction of special mechanisms which require the visitor to do little more than to press a button or to turn a crank.



Colonial Print Shop

Reminiscent of Franklin's printing activities

The personal relics of Franklin are displayed in the great Memorial Hall, in the center of which is the statue, and associated items are shown in the nearby Hall of Honor. In this latter hall are displayed apparatus and appliances associated with several famous scientific workers. The exhibits include Priestley's air pump, material used by Faraday in his electromagnetic discoveries, mementoes of Edison and his three-wire generator first used for street lighting, Elihu Thomson apparatus, a first Fleming radio tube, original De Forest audions, and early Zworykin television tubes.

While the Fels Planetarium offers reproductions of the skies in any weather, visitors who desire to study the celestial bodies may do so, weather permitting, in one of the finest observatories open to the public.

Refracting and reflecting telescopes are available, and the adjoining hall contains a number of astronomical exhibits of historical and instructive nature.

Franklin was famous as a printer and a prosperous papermaker. It is only natural, then, that these industries should be adequately represented in a museum devoted to his life and work. Paper is made on an exact replica of a Foudrinier machine under the constant scrutiny of visitors. Much of the printing required by various departments of the Institute is also done by skilled craftsmen as part of the Museum's demonstrations of industrial processes.

Franklin's interest in electricity which enabled him to establish a worldwide reputation as a scientist receives a great deal of attention. Apart from specimens of his own apparatus, the student will gather

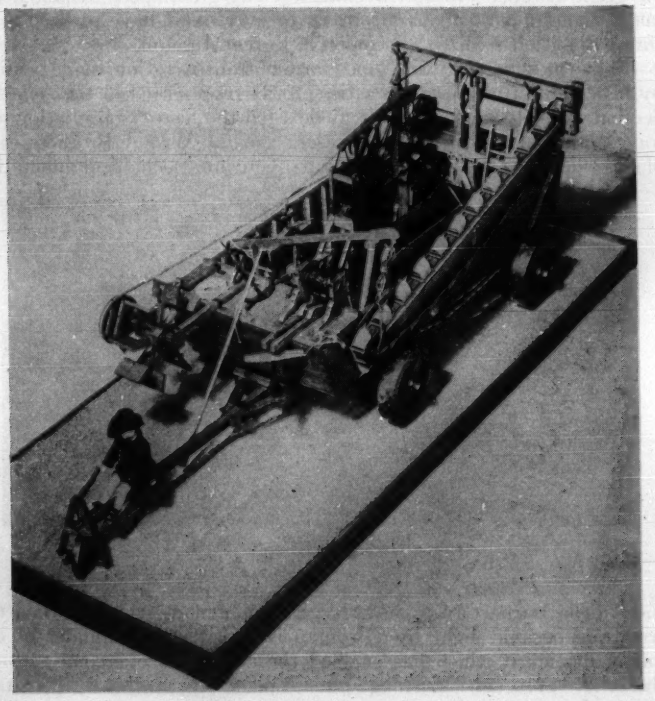
The electric spark

much information upon electricity, electromagnetism, and electronics from the wide variety of other exhibits. These range from highly scientific material to the manifold applications of electricity and magnetism in industry and communications. Especial attention is devoted to those applications, like the telephone, most familiar to the visitor.

Other fields in physical science are also treated, the fundamental principles being explained by simple experiments and demonstrations, while innumerable applications will be found in different sections. The science of mechanics, in particular, plays an important part in everyone's life, so that care has been taken to present simple explanations of the more commonly applied principles in order that the practical applications might be better understood. The other branches of physical

science are adequately treated, a series of darkened rooms provides many illustrations which help in the understanding of the principles of light, especially in the recently developed phases of fluorescence.

The Marine Transportation section is a well co-ordinated effort to illustrate the story of America's association with the sea. A series of exquisite scale models which never fail to arouse admiration shows the



Amphibolis Orukter

Model of the first steam driven land vehicle in the United States

evolution of the ship from the time the continent was first discovered down to the most recent developments, represented by a remotely controlled vessel. Navigation instruments aid in recalling the courage and faith of the early navigators who had to resort to inspired guesswork on long voyages, and bring the story down to the precision instruments with which the modern navigator finds his way over the oceans. The United States Navy has contributed instruments employed upon

modern vessels and these have permitted the construction of a pilot house similar to that which is found on ships of today.

Various forms of land transportation are displayed, either with the aid of models or by actual specimens. Conspicuous among these is the giant locomotive. Incredible as it may seem, the visitor may climb into the engineer's cab and literally drive this 350-ton monster. No great distance will be travelled, nor any great speed attained, but many thousands of "boys" from six to over sixty, have realized a life time's ambition to drive a locomotive in the Museum.

Man's most recently developed form of transportation, made possible by his conquest of the air, is satisfactorily represented in the Aviation Section. Finely executed scale models tell the history of aviation and some actual historical airplanes (as one of the Wright Brothers early planes) illustrate the pioneer efforts to overcome mechanical difficulties,

Link Trainer

Aspiring aviators learn how to control an airplane

and Amelia Earhart's Lockheed "Vega" monoplane which marked the first trans-oceanic flight by a woman is a perpetual reminder of the courageous spirit which has enabled the aviator to overcome natural obstacles. A recent "Mustang" pursuit plane is accessible to all visitors who desire to climb into the cockpit and try out the controls. This section exercises a peculiar but understandable fascination for young people. As in all the other sections of the Museum they come, not to see but to do. "Push button" exhibits demonstrate the principles of aerodynamics to the studious but the enthusiasm of youth finds its happiest outlet in enjoying the means for simulating the conditions of actual flight. Special training apparatus renders this possible. In these the visitor is afforded the experience of controlling an airplane under flight conditions without leaving the ground. When he has learned to master the simple controls on the beginners' trainer, he can pass to a

more advanced test where his control is recorded as he attempts to pursue a moving target, and finally he can test his skill in ascending from or landing on an airstrip or the deck of a carrier. A monthly competition with a tempting reward of real flight has been instituted for the encouragement of young visitors.

The Chemistry Section is spread over several rooms and represents some of the finest examples of industrial co-operation in the support of the Museum. Fundamental chemistry reactions and experiments, with the requisite automatic measuring of materials, are performed before the visitor's eye in response to the pressure on an electric button. From these the visitor passes to exhibits of industrial applications of

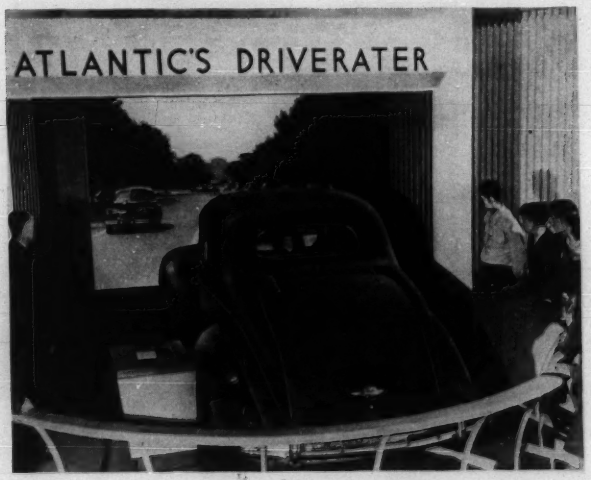
Rubber

The story of rubber is told in this room

chemistry. One of the nation's principal industries is the refining of petroleum. A model oilfield shows the geological structure, the drilling of a well, and the methods of extracting oil. The refining processes are illustrated in an admirable manner by an installation constructed entirely of glass, which enables the visitor to see conditions and processes that are normally concealed from sight. In view of the diversity of products derived from petroleum, the methods by which the main derivatives are separated and the manner of "cracking" to secure more gasoline from a given volume of petroleum are shown in the reproduction of the refinery.

Adjacent to this room is one in which is shown another fundamental

industry that has grown to major proportions during recent years, that which is concerned with rubber. Here the story of natural and synthetic rubber is told in a manner which reveals modern museum techniques at their best. Light, color, and motion are employed to tell how rubber is obtained, how processed, and how used. The qualities of rubber and how these qualities are put to special uses to contribute to safety, comfort, and utility are demonstrated in a number of operating exhibits. A large illuminated flow chart tells serially how rubber is processed in the manufacture of tires for all kinds of automotive vehicles. A synchronized talk is reproduced to explain the sequences in the production of a tire's several parts.



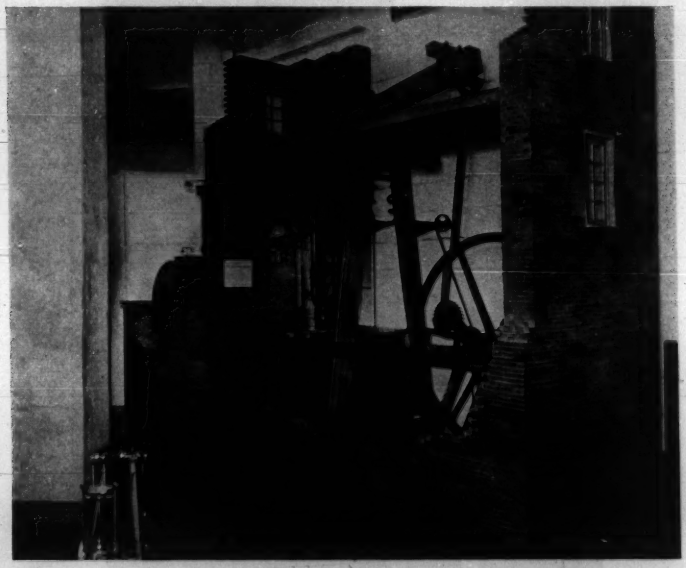
Driverater

Skill and road manners of automobile drivers are tested
(*Photo by News Reel Laboratories*)

The products of rubber and petroleum combine in the automobile and, as this is one of the most prevalent interests in modern life, furnishing both transportation and pleasure, it is deserving of the special attention it receives in the Museum. Visitors are permitted to test their driving skill and road manners in a most realistic fashion. Actual driving conditions are simulated by seating the driver in a real automobile and confronting him with a series of average traffic incidents which are unfolded in full scale by means of a motion picture. The driver is asked to use the necessary controls required to meet the situations presented to him, and his reactions are automatically recorded

so that his qualifications as a driver may be judged. The impartial record of his performance is handed him without comment.

Those forms of Prime Movers which have been used in industry from the time when Newcomen invented the atmospheric engine down to the modern steam turbine and electric power generation are shown in a collection of models and actual machines. Numerous examples of the skilled mechanics' craft and their special adaptations contributing to the perfection of mechanisms are displayed.



Watt Engine

Scale model of Watt's "Sun and Planet" engine

These are but a few of the many features of the Museum's permanent exhibitions. In addition to these, the visitor's interest is kept alive by the arrangement of special exhibitions of a temporary nature relating to matters of topical concern. These exhibitions frequently take the form of displays of industrial products but others are designed to explain new scientific discoveries, while still others are outstanding examples of hobby displays in which a scientific or a mechanical skill is required.

In order to extract the maximum value from the exhibit, material recourse is made to special demonstrations presented by the staff of demonstrators. Part of their work is to operate those exhibits which

call for special technical knowledge or skill. The presentation of the special exhibitions and demonstrations enables the staff to make of the Museum a truly living memorial of Benjamin Franklin since the material offered reflects the continuity of technical progress in all its stages. The frequency of the changes is sufficient to restrain anyone

Automaton

An exceptionally fine example of mechanism by Henri Maillardet

from saying truthfully that they have "seen the Museum." There is always something new and worthy of attention.

When the functions of the Institute assumed new complexities, Dr. Allen's official duties were re-arranged in such manner that his office as

Director of the Museum had to be delegated. His successor in this office was Mr. A. C. Carlton who had received a technical training as a metallurgist and who had gained experience in museum techniques at the Chicago Museum of Science and Industry. This change relieved Dr. Allen of some duties and permitted him to devote more time to the direction of the Institute's research program which, we shall presently see, had enormously expanded.

That this new type of museum fulfills its function as an adjunct to classroom training is best shown by the throngs of students who are brought to its various sections from schools, not all of which are in the immediate vicinity. Students are brought from considerable distances

The Telephone

Model of the exhibit to tell the story of the telephone
(*Photo by Tyler Fogg*)

to benefit from the simple manner in which technical subjects are presented for their understanding. The instruction of organized groups is materially aided by the work of the Museum Education Department which furnishes teachers with the aids and guidance necessary to supplement the visit to the Museum with the appropriate classroom work. That young visitors do not regard their class visits as part of the tedium of schoolwork is testified by their attendance in large numbers on Saturdays, when they come voluntarily as individuals.

The work of the Museum as an aid to visual education and as a stimulant to those who seek self-improvement has met with such high

appreciation from educators that the State Legislature has appropriated an annual fund to help in its work. It is noteworthy that this is the only sum paid from public funds to the Institute's income.

It must not be supposed, however, that the sole purpose of the Museum is to cater to the needs of its juvenile visitors. The material so lavishly displayed in its various sections plays an important part in adult education, presenting technical exhibits in a manner which makes them easily comprehensible to those whose instruction too often ends with their formal education. The Museum attracts adults who have no technical employment but who wish to be instructed in the contributions of technology to the efficiency and enrichment of modern living, and it enables the expert in one field to keep abreast of parallel developments in other fields. The purpose of the Museum was to be an agency contributing to the visual education of visitors of all ages and it is maintained as such, giving attention to the requirements of individuals and groups of different aptitudes and skills. The reputation of The Franklin Institute has been extended through this Museum, for letters of inquiry come from all parts of the world asking for information upon historical and technical subjects. Most of these inquiries have been prompted by enthusiastic accounts of the Museum given to the writers by visitors from distant places.

Industrial concerns have shown their appreciation of the Museum's work by contributing generously toward the installation and maintenance of expensive displays which add materially to the attractiveness of the Museum. Efforts are made toward expanding this field of industrial co-operation in order that the exhibits may always be representative of the nation's progress.

The maintenance of this great Museum does not represent the only enlargement of The Franklin Institute's policy during recent years. Fundamental and practical research has always been a prominent feature of its activities and participation in this work had been limited only by the opportunities and the available funds. After the establishment of the Bartol Research Foundation the Institute's research activities were extended when it assumed trusteeship in 1935 of The Biochemical Research Foundation. This foundation consists of a group of investigators who are actively engaged upon problems of a biochemical nature, especially in the field of cell growth and reproduction. It receives financial support from a philanthropist who desires to encourage research in this important field. The Foundation's laboratories are adjacent to the campus of the University of Delaware at Newark, Del.

An unprecedented development of the Institute's research activities was evoked by the outbreak of the Second World War. The grim realities of the needs of national defense could not be evaded with the realization of the changed nature of warfare which had assumed a strong

scientific character. The entire resources of the Institute were thrown into the public service. The members of the excellent technical staff who had been assembled to administer the Museum were promptly engaged in the conduct of mechanical, optical, and electrical research for the purpose of improving the weapons and instruments upon which the military and naval services were dependent for the successful conduct of operations. The national Office of Scientific Research and Development allotted to them tasks which increased in severity as the conflict progressed, and the small original staff was progressively increased as the work expanded in volume, diversity, and complexity. This staff was fortunate in having at its disposal an excellent machine

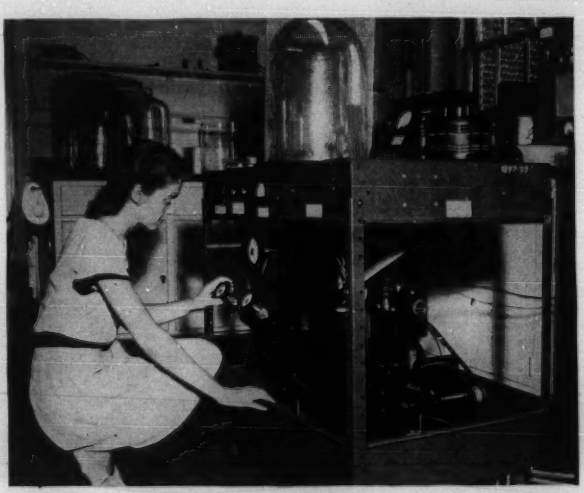
Adjusting friction wheel and prod-mover assembly

shop where the necessary apparatus for the conduct of research could be constructed and where experimental models could be made under the personal supervision of the staff. Before the war had ended the newly founded laboratories were occupying 9000 square feet of space formerly occupied by museum exhibits and work rooms.

The first project for investigation related to the problems concerning air borne fire control. This field rapidly expanded until it embraced five groups employing one hundred and twenty-five persons, of whom thirty-five were scientists. Altogether twenty-five major projects were investigated by these groups resulting in the design, development, and construction of test items for directing torpedoes, bombs, rockets from airplanes, and bullets. The final report upon the investigation com-

prised ten large volumes embracing work performed for Naval Ordnance, the Army Air Force, the Bureau of Aeronautics, and the National Defense Research Council. The contribution of the groups to the national war effort was recognized in 1945 when the Chief of the Bureau of Ordnance, United States Navy (Vice-Admiral G. F. Hussey, Jr.) visited the Institute to present the Naval Ordnance Award, with its accompanying certificates for the individual workers.

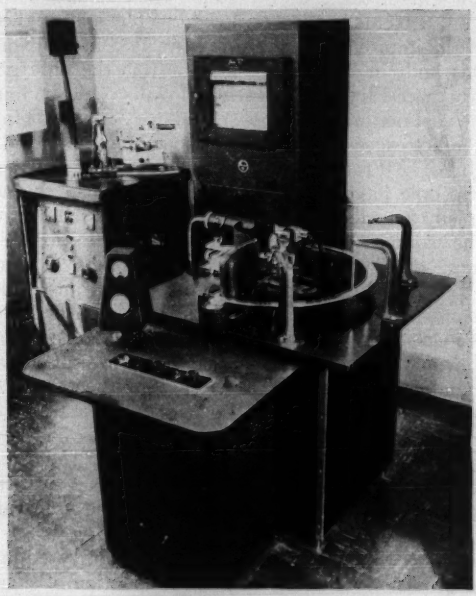
This project had scarcely enough time to swing into action before the Institute received another contract for the performance of research work. This had to deal with the basic problems involved in the development of higher fire power in small arms. Before any tests could be



High vacuum units in the laboratories

undertaken in this project it was necessary to construct an experimental gun of small caliber which would withstand much higher pressures than those to which standard weapons were subjected. Tests were made under rigidly controlled conditions on a firing range constructed in the basement of the building. A staff comprising twenty-three members was employed upon this project and a special machine shop staff had to be assembled to assist in the work. The ammunition tested was hand weighed and loaded into especially made cartridge cases; barrels were gaged to determine the wear; and the behavior of bullets was examined. Velocities of the projectiles and maximum powder pressures were determined. Complicated problems of interior ballistics had to be solved for each propellant used, and the erosive qualities examined.

In June, 1942, an additional research project was undertaken for the Technical Division of the Office of the Chief of Ordnance, United States Army, relating to the problems of artillery design. This project was organized into three sections, the Analytical, the Carriage, and the Cannon sections. These provided employment for fifty persons. In addition to carrying out the design work on new types of major caliber weapons, these groups were engaged in certain fundamental studies and analyses of gun design. Subjects beyond the scope of existing text-books were dealt with, including the stability of cannon mounted on track-laying vehicles; the effect of rifling torque on gun carriages; an



X-Ray Diffraction Equipment

exhaustive discussion on cold worked gun tubes; the theory of volute springs; the theory of double recoil mechanisms; recoilless weapons of major calibers; and the theoretical analysis of torsion bar suspension.

Those who worked tirelessly but successfully upon these Ordnance problems had their reward when The Franklin Institute was awarded the Ordnance Distinguished Service Award in 1944. The presentation was made personally by the Chief of Ordnance (Lieut.-General L. H. Campbell, Jr.) an act of courtesy appreciated by those whose labors had led to the award.

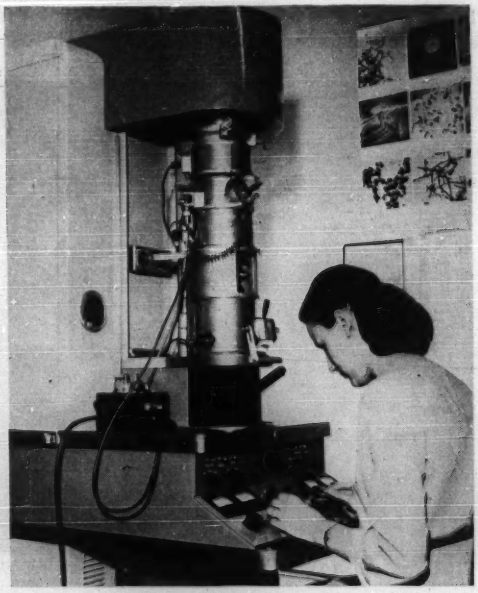
Meanwhile the two strongholds of the Institute's research activities were deeply involved in investigations surrounded by closest secrecy. At the Bartol Research Foundation full use was made of the staff's unusually wide and intensive knowledge of fundamental physics. Some of the more obstinate features of radar improvement and Loran trainer development were overcome in their laboratories; problems relating to the theory and application of electricity and magnetism were solved; certain types of computing apparatus for airplane pilots were developed; and some involved problems of ballistics were resolved. Some of their problems were inherited as portions of a major design but, as the solutions were presented, the results justified their elevation to the stage of being major problems in their own right. The staff rejoiced to learn that some of the improved radar equipment used in the North African campaign was built in their shop, since it was the only place at the time where the necessary concentration of skills could be found.

But to the vast majority of people no military operation in the world-embracing conflict exceeded in interest the achievement and use of the atomic bomb. The Franklin Institute played a part in that achievement. Few people have realized that every step in the accomplishments which led to nuclear fission was attended by the mystery of how to protect the workers from the effects of the radiations their labors would produce. Satisfactory progress in the practical work was attained only because knowledge of the protection against radio-activity was one step in advance. While one group of scientists toiled to apply the effects of nuclear energy, another group strove to develop the safety phases which would protect the former group. No staff of investigators was better qualified to conduct researches in the effects of nuclear energy than was the staff of The Biochemical Research Foundation. This group of scientists under Dr. Ellice McDonald had been concentrating since 1938 upon the physiological effects of radiations. Their 15,000,000 volts cyclotron was powerful enough to furnish the neutron radiation for experimental work connected with the preparation of the nuclear fission.

A new building was erected where supplementary equipment was installed and provision made for the accommodation of small animals. The cyclotron was employed to produce radiations to which the animals, in especially designed air conditioned cages, were exposed to predetermined intensities and in controlled dosages. Periodical examinations were made to test the effect of neutron radiation upon the blood of the treated animals. The work of The Biochemical Research Foundation upon neutron radiation neither began nor ended with research in connection with the atomic bomb. The investigation of the pathological effect of radio-activity was but supplemental to a study which has engrossed a portion of the staff since the inception of the Foundation—the development of a successful treatment for cancerous growths.

These steadily progressed with the investigation into the mechanism of radiation with the object of pressing forward its employment in the explanation of vital processes.

The war set precedents in public service for many organizations, but public service has been a tradition of The Franklin Institute for a century and a quarter. The effort had been extended to meet an emergency, when there was no time for calm reflection, but only an urgent pressure for the production of results. When an organization can arise to meet a crisis there is a bright prospect that, once the



Examining sample with Electron Microscope

panorama of war has run to its end, the staff could enter upon a planned future with a confident vision of bold new ventures in physics, chemistry and engineering. Such has been the case with The Franklin Institute. As soon as its contracts for the accomplishment of immediate military needs had been cleared away, the organization of a well equipped laboratory was undertaken so that the Institute might play a larger part in research as a peacetime industrial requirement. The outcome is The Franklin Institute Laboratories for Research and Development. The laboratories are housed partly in the main building and partly in

the rejuvenated old Court House adjoining. They occupy approximately 43,000 square feet of space and provide employment for a staff of nearly three hundred persons. The equipment is of the most modern nature and is constantly being added to with the purpose of enlarging its scope and increasing its efficiency. Among its special features are an electron microscope and an installation of the latest type for testing the strength of materials.

Additions to its facilities are still regarded as a suitable manner of establishing memorials to men who have gained a reputation in specific fields of scientific or industrial activity. An interesting example of this is the Halstead Photoelastic Laboratory, established for research on the stresses in structures by the use of polarized light, as a memorial

Universal Testing Machine

to David Halstead by his widow, Irene Halstead, a descendant of the Thomas Scattergood who signed the roster of members on the night The Franklin Institute was founded.

The laboratories are equipped and staffed in a manner which enables them to undertake research of a fundamental nature to benefit industry. Commercial firms find it convenient to entrust their research problems to the especially qualified staff with the assurance that the results will be in accordance with the standards which have placed and maintained The Franklin Institute in the front rank of technical institutions for more than a century.

On April 20th, 1949, the Institute celebrated its 125th anniversary with appropriate ceremonies. The Museum arranged for the exhibition of numerous examples of exhibits illustrating the development of the science of electricity, since the time corresponded to the 200th anniversary of Benjamin Franklin's performance of his historic electric experiments. Visitors to this display had the opportunity of seeing the growth of the entire science from its fundamental physical principles to the application of some of the most advanced applications of those principles. Guests at the celebration ceremonies were taken for an inspection tour of the research laboratories.

Behind these unusual features, the work of the Institute goes on without interruption. On the day of its founding in 1824 between four

Dr. Robert A. Millikan, Nobel prizewinner, speaking at the 125th Anniversary meeting of the Institute

and five hundred men expressed their desire to become members of the Institute. Today, there are about 5500 members. Control of the Institute rests in the membership. The President, four Vice-Presidents, and the twenty-four members of the Board of Managers give their time and the benefit of their wide experience without remuneration. The present President, Mr. Richard T. Nalle, has an unusually extensive business and technical experience which, with other qualities of mind, enables him worthily to uphold an office that has been held in succession by men of distinction. Most of the current activities date from the time the Institute was founded. The Committee on Science and the

Arts, the lectures, the library, research, and the JOURNAL (now entering upon its two hundred and forty-ninth volume) are all in flourishing condition. The other activities have developed gradually as the need and the proper method of providing for them required.

Viewed in retrospect, the one hundred and twenty-five years of the Institute's existence have been profitable to individual members and to the community they serve. Born of a need that is not bounded by time, The Franklin Institute accepted a mission which extends indefinitely into the future. The aim of its founders was high, but not so high that it was beyond the means of accomplishment, provided the men could be found to carry it forward. It has been the fortunate experience of the Institute to find an unbroken sequence of the right type of men from among its members. The staff, who work under the direction of the Board of Managers, is aware that much remains to be done in the provision of services that would be of high value, but these must await the time when funds and facilities are available.

A NOTE ON THE NOTCH EFFECT OF METALS

BY

K. MINAMIŌZI[1] AND H. ŌKUBO[2]

The theory of elasticity shows that the stress concentration around a diametrical hole of round bars under tension, increases as the diameter of the hole decreases and when the diameter of the hole decreases infinitely, the stress concentration factor approaches 3.[3] On the other hand, the fatigue tests of metals show that the strength of a bar with a very small diametrical hole does not differ perceptibly from that of a solid one. We find the classical theory insufficient to explain this phenomenon. In this paper, a new consideration will be introduced and the experimental result obtained by fatigue tests of round bars with a small diametrical hole, will be explained theoretically.

Reports on the influence of the diametrical hole on the endurance limit of round bars have abundantly appeared in publications, but few of them treated the case of a small diametrical hole. Upon this, we used specimens with a small diametrical hole in each, varied in diameter from 0.0138 to 0.0787 in. Holes were drilled very carefully and their diameters were measured on a Zeiss comparator. Specimens of several kinds of metals were used such as mild steel, special steel and super-duralumin.

Symbols Used

σ_x, σ_y	normal stresses on lines perpendicular to x and y axes,
σ_0	normal stress at large distances from the center of the hole,
τ	shearing stress,
$\bar{\tau}$	mean shearing stress in the interval h,
d	diameter of the test specimen,
δ	diameter of the hole,
h	interval in which the mean value of shearing stress is considered; it is a constant which chiefly depends on the size of crystals of the metal, and
k	stress concentration factor.

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[2] Institute of High Speed Mechanics, Tohoku University, Sendai, Japan.

[3] R. E. PETERSON AND A. M. WAHL, "Two- and Three-Dimensional Cases of Stress Concentration, and Comparison With Fatigue Tests," *J. Applied Mechanics*, Vol. 3, No. 1, p. A–15 (1936).

The mechanical properties of the metals are tabulated in Table I:

TABLE I

	Yield Strength, psi. × 10^4	Ultimate Strength, psi. × 10^4	True Breaking Strength, psi. × 10^4	Elongation, Per Cent	Reduction of Area, Per Cent
Mild steel	2.99 (lower)	5.82	12.1	39	62
Special steel	6.97 (0.2%)	10.95	21.9	27.9	63
Super-duralumin	3.37 (0.2%)	5.53	8.2	23	40

Fatigue tests were done using Haigh's testing machine. The sketch of the specimen is shown in Fig. 1. The fatigue data obtained in connection with the above mentioned program are given in the Tables II, II, and IV.

FIG. 1.

TABLE II.—*Mild Steel* (d = 0.1969 in.)

Diameter of Hole, in.	Nominal Stress,* psi. × 10^4	No. of Repetitions (10^3)	Remarks
$\delta = 0$	2.56	0.94	broken
	2.49	1.90	broken
	2.42	2.69	broken
	2.35	10.01	unbroken
$\delta = 0.0138$ $= 0.07d$	2.13	1.65	broken
	2.06	3.34	broken
	1.99	3.28	broken
	1.92	8.04	broken
	1.85	12.80	unbroken
$\delta = 0.0197$ $= 0.10d$	1.85	1.35	broken
	1.78	2.77	broken
	1.71	8.33	broken
	1.64	10.00	unbroken
$\delta = 0.0394$ $= 0.20d$	1.71	0.70	broken
	1.64	0.84	broken
	1.56	2.96	broken
	1.49	11.33	unbroken
$\delta = 0.0787$ $= 0.40d$	1.64	0.92	broken
	1.56	4.28	broken
	1.49	6.90	broken
	1.42	10.00	unbroken

* As the value of nominal stress, we take the mean value of the normal stress on the net cross section through the central axis of the hole.

TABLE III.—*Special Steel* ($d = 0.1575$ in.)

Diameter of Hole, in.	Nominal Stress,* psi. $\times 10^4$	No. of Repetitions (10^6)	Remarks
$\delta = 0$	4.41	0.33	broken
	4.34	2.17	broken
	4.27	3.20	broken
	4.19	4.51	broken
	4.12	10.00	unbroken
$\delta = 0.0138$ $= 0.0875d$	3.06	0.38	broken
	2.99	1.34	broken
	2.92	1.49	broken
	2.84	10.02	unbroken
$\delta = 0.0197$ $= 0.125d$	2.99	0.52	broken
	2.92	1.40	broken
	2.84	1.42	broken
	2.77	10.00	unbroken
$\delta = 0.0394$ $= 0.25d$	2.99	0.21	broken
	2.92	0.92	broken
	2.84	6.01	broken
	2.77	10.00	unbroken

* See footnote to Table II.

TABLE IV.—*Super-duralumin* ($d = 0.1969$ in.)

Diameter of Hole, in.	Nominal Stress,* psi. $\times 10^4$	No. of Repetitions (10^6)	Remarks
$\delta = 0$	1.49	0.82	broken
	1.42	1.78	broken
	1.35	2.75	broken
	1.28	10.00	unbroken
$\delta = 0.0157$ $= 0.08d$	1.00	1.44	broken
	0.92	1.35	broken
	0.85	4.58	broken
	0.78	10.00	unbroken
$\delta = 0.0197$ $= 0.10d$	1.00	1.43	broken
	0.92	1.81	broken
	0.85	4.64	broken
	0.78	10.00	unbroken
$\delta = 0.0394$ $= 0.20d$	0.78	0.40	broken
	0.71	1.26	broken
	0.64	1.75	broken
	0.57	10.01	unbroken
$\delta = 0.0591$ $= 0.30d$	0.78	0.73	broken
	0.71	0.81	broken
	0.64	3.08	broken
	0.57	10.00	unbroken

* See footnote to Table II.

It is well known that with increase of the diameter of a hole the endurance limit of a test specimen shows gradual increase accordingly when the diameter of a hole is larger than a certain limit. But the results shown in the above tables show that when the diameter of the hole is very small, the conclusion is quite contrary, viz., with increase of the diameter of the hole the endurance limit decreases.

To represent the results graphically, we introduce a term k, stress-concentration factor, defined as

$$k = \frac{\text{endurance limit for specimens without holes}}{\text{endurance limit for specimens with a hole in each}}.$$

Figure 2 shows the relations between the stress-concentration factor and the diameter of a hole for several kinds of metals.

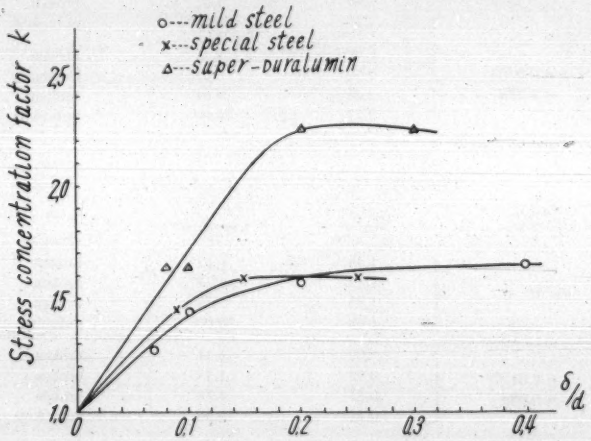

FIG. 2.

Classical theory fails in the explanation of the experimental results obtained here when the diameter of the hole is very small. The cause of this discrepancy between the theoretical and the experimental results is that the theory of elasticity assumes the material to be perfectly homogeneous and isotropic while the metals in practical use are neither homogeneous nor isotropic. The assumption is valid when the size of crystals of metals is infinitely small. From the microscopic standpoint, it may be supposed that there are irregularities of stress distribution even in specimens without holes, while the endurance limit is determined by using mean values of the stress without any consideration of this fact. If the classical theory were valid generally, there may be the case where the strength of a certain specimen is three times that of the

other specimen of the same kind, since we cannot distinguish solid specimens from those with infinitely small holes. Upon this, we can conclude that when we determine the endurance limit, we must consider the mean stress in a certain area around the point instead of the stress at a point when the diameter of the hole is not very large compared with the size of crystals of metals.

To correct the theory so as to meet the experimental results, we shall introduce a new consideration based on the following assumptions:

(*a*) The material fails by shearing stress and its magnitude is given by the mean value in a certain interval, determined by the kind of metals (for the convenience of calculation, we shall take the mean value of stress in a certain interval on a line in place of that in the area).

(*b*) To simplify the calculation, the diameter of a hole is assumed to be very small and hence the stress distribution around the hole is considered to be the same as that of an infinite plate with a circular hole.

We shall consider an infinite plate with a circular hole of radius $\frac{1}{2}\delta$ and submitted to uniform tension in the x direction (see Fig. 3). If we

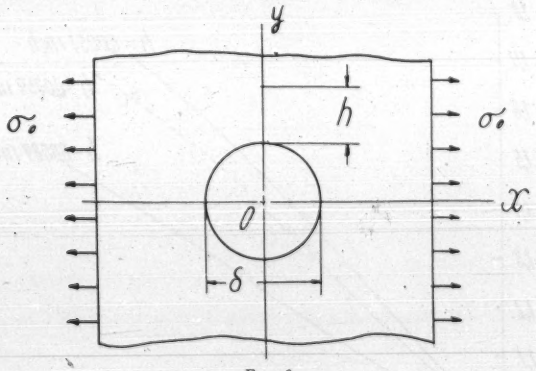

FIG. 3.

denote the tensile stress at large distances from the center of the hole by σ_0, the stress components on the y axis are given by[4]

$$\left.\begin{aligned}\sigma_x &= \sigma_0\left(1+\frac{\delta^2}{8y^2}+\frac{3\delta^4}{32y^4}\right),\\ \sigma_y &= \frac{3\delta^2}{8}\left(\frac{1}{y^2}-\frac{\delta^2}{4y^4}\right)\end{aligned}\right\}. \qquad (1)$$

Since σ_x, σ_y in Eq. 1 are principal stresses, the shearing stress on the

[4] S. TIMOSHENKO, "Theory of Elasticity." New York, McGraw Hill, 1934, p. 75.

line inclined 45° with respect to x axis is

$$\tau = \tfrac{1}{2}(\sigma_x - \sigma_y) = \frac{\sigma_0}{2}\left(1 - \frac{\delta^2}{4y^2} + \frac{3\delta^4}{16y^4}\right). \tag{2}$$

The mean value of τ in the interval h along the y axis is

$$\bar{\tau} = \frac{1}{h}\int_{\delta/2}^{\delta/2+h} \tau dy = \frac{\sigma_0}{2}\left\{1 + \frac{2\delta^2(\delta + h)}{(\delta + 2h)^3}\right\}. \tag{3}$$

At large distances from the center of the hole, the shearing stress is $\frac{1}{2}\sigma_0$ and hence the mean value of the shearing stress in the interval h is also $\frac{1}{2}\sigma_0$. As the cause of the failure of metals, if we consider the mean value of the shearing stress in the interval h according to the assumption (a), then the stress-concentration factor is

$$k = \frac{\bar{\tau}}{\sigma_0/2} = 1 + \frac{2\delta^2(\delta + h)}{(\delta + 2h)^3}, \tag{4}$$

where the constant h is determined by the kind of metals. We shall determine the constant using the fatigue data previously mentioned.

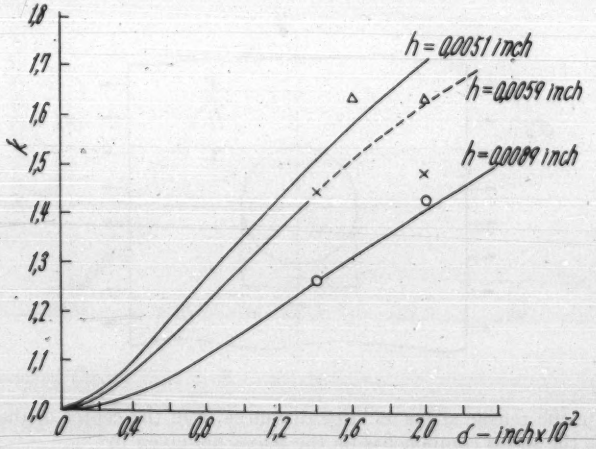

FIG. 4.

Figure 4 shows the relations between the stress-concentration factor and the radius of the hole for several values of h. From the figure we can determine the constant h for each metal as (approximately)

mild steel	0.0089 in.
special steel	0.0059 in.
super-duralumin	0.0051 in.

Starting from the problems of sharp notches, a similar consideration was introduced by H. Neuber.[5] But we must point out the fact that the validity of the classical theory does not depend on the sharpness of notches, but on the magnitudes of notches relative to the sizes of crystals of which the material consists.

[5] H. NEUBER, Kerbspannungslehre, S. 142 (1937).

Tough, Light, Noncorrosive Fiber-Glass Pipe, which may partially replace metal pipe, is being tested by the Army's Engineer Research and Development Laboratory at Fort Belvoir, Va. Especially promising for field petroleum distribution, the translucent pipe is made of noncritical materials—sand and synthetic resin—and is easy to manufacture, though costly at present. A 20-ft. section weighs about one-fifth as much as the same size in steel.

Dye-Tube Spindle Eliminates Dye Trapping (*Textile World*, Vol. 99, No. 10).—A drawn stainless-steel shape to replace fabricated dye-tube spindle shafts, has been developed by Armco Steel Corp., Middletown, Ohio. This special shape is said not only to simplify manufacture of spindles, but also to insure utmost corrosion resistance.

With the drawn stainless-steel shape, the only operation required to produce a spindle shaft is cutting the shape to proper length. This operation replaces forming the shaft body by machining or by welding several sections together. Elimination of welding is especially advantageous, since warping of welded shafts sometimes requires a straightening operation.

Because the smooth, continuous surfaces of the drawn spindle shaft permit complete draining, dye cannot become entrapped to corrode the metal and stain the yarn.

The spindle is available in Type-316 Armco stainless steel for use in sulphuric-acid dye solutions, as well as in other grades of stainless for use in less corrosive dyes.

Mechanization of Cotton Moves Ahead.—Mechanization of the cotton crop is a step nearer this fall as the result of a unified, across-the-board program of research now in its second year that involves work by engineers and scientists in 15 Southern States.

The full-scale effort, made possible by the Research and Marketing Act of 1946, is designed to bring complete mechanization of all phases of cotton production from disposal of previous crop residue through preparation of the seedbed and control of weeds to stripping or picking, storage and ginning. Agricultural engineers of the U. S. Department of Agriculture who are spearheading the program point out that complete mechanization from start to finish is the objective so that more uniform high-quality cotton may be produced per worker at a low cost competitive with the cheap labor available in other cotton producing areas of the world. It also will involve mechanization of other crops normally planted in rotation with cotton so that farmers can use their equipment with economy and efficiency every year.

Cotton, a major crop in all the Southern States, is not now generally mechanized. It requires about five times as much hand labor as wheat and about 3½ times as much as corn to produce a given gross income. Until the coordinated research program got under way, investigations directed toward mechanization of the crop were piecemeal and without regional unity.

The new program integrates the entire field with individual States taking certain segments, and farm machinery and cotton gin manufacturers and the agricultural chemical and fertilizer industries cooperating. Research on varietal and other plant problems related to mechanization, such as defoliation, is also under way in the various States, with parallel engineering studies aimed at development of more effective equipment and operating methods.

THEORETICAL LIMITATIONS ON THE BROADBAND MATCHING OF ARBITRARY IMPEDANCES*

BY

R. M. FANO[1]

ABSTRACT

This paper deals with the general problem of matching an arbitrary load impedance to a pure resistance by means of a reactive network. It consists primarily of a systematic study of the origin and nature of the theoretical limitations on the tolerance and bandwidth of match and of their dependence on the characteristics of the given load impedance. Necessary and sufficient conditions are derived for the physical realizability of a function of frequency representing the input reflection coefficient of a matching network terminated in a prescribed load impedance. These conditions of physical realizability are then transformed into a set of integral relations involving the logarithm of the magnitude of the reflection coefficient. Such relations are particularly suitable for the study of the limitations on the bandwidth and tolerance of match. Definite expressions for these quantities are obtained in special cases. The practical problem of approaching the optimum theoretical tolerance by means of a network with a finite number of elements is also considered. Design curves are provided for a particularly simple but very important type of load impedance. In addition, a very convenient method is presented for computing the values of the elements of the resulting matching network.

1. THE MATCHING PROBLEM

The transfer of power from a generator to a load constitutes one of the fundamental problems in the design of communication systems. A problem of this type involves in every case the design of a lossless coupling network to transform a given load impedance into another specified impedance. One refers to this operation as "impedance matching." In most practical cases this problem can be idealized as indicated in Fig. 1. The generator is assumed to consist of an ideal voltage source in series with a pure resistance; maximum power transfer is then obtained when the impedance presented to the generator is equal to the source resistance.

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The work presented in this paper is part of a thesis with the same title submitted by the author in partial fulfillment of the requirements for the degree of Doctor of Science at the Massachusetts Institute of Technology (June, 1947). A summary was presented to the National Electronics Conference in Chicago on November 3, 1947.

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It will be shown later that it is not possible to match an arbitrary impedance to a pure resistance over the whole frequency spectrum, or even at all frequencies within a finite frequency band. On the other hand, it is evidently possible to obtain a match at any desired number of frequencies, provided the given impedance has a finite resistive component at those frequencies. Such a matching, however, has little practical value because it is incorrect to assume that one can obtain a reasonable match over a frequency band by correctly matching at a sufficiently large number of frequencies within the desired band.

It becomes clear at this point that the statement of any matching problem must include the maximum tolerance on the match as well as the minimum bandwidth within which the match is to be obtained. Furthermore, it is reasonable to expect that, for a given load impedance and a given maximum tolerance, there is an upper limit to the bandwidth that can be obtained by means of a physically realizable coupling network. It follows that an investigation of such a limit should be the first step in any systematic study of matching networks. Before this

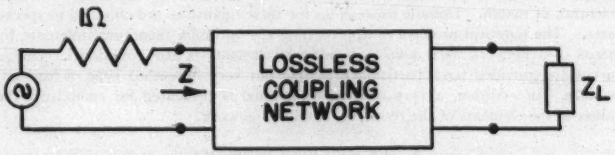

FIG. 1. Matching network for an arbitrary load impedance.

problem can be stated in a precise manner, however, one must define an appropriate measure of the match so as to give to the tolerance a definite quantitative meaning.

In view of the fact that matching is used to maximize the load power, it appears reasonable to measure the match in terms of the actual load power P_L divided by the maximum power P_o that could be delivered by the generator. Actually, the most convenient quantity for this purpose is the per unit power rejected by the load, that is

$$|\rho|^2 = 1 - \frac{P_L}{P_o}. \tag{1}$$

It will be recognized that ρ is the reflection coefficient defined by

$$\rho = \frac{Z - 1}{Z + 1},$$

where Z is the impedance presented to the generator as indicated in Fig. 1.[2] If the generator were connected to the coupling network by a transmission line of characteristic impedance equal to the source re-

[2] In Fig. 1, as well as in the rest of this paper, all the impedances are normalized with respect to the source resistance unless otherwise stated.

sistance, the voltage standing-wave ratio on the line would be given by

$$VSWR = \frac{1 + |\rho|}{1 - |\rho|}. \tag{2}$$

The problem of the broadband matching of an arbitrary impedance can now be stated as follows. With reference to Fig. 1, Z_L is a given impedance function of frequency, subject only to the restriction of being realizable by means of a finite number of linear passive elements. A nondissipative coupling network must be designed such that, when terminated in Z_L, the magnitude of the input reflection coefficient is smaller than, or equal to, a specified value $|\rho|_{max}$ at all frequencies within a specified band.

The exclusion from the system of distributed-constant elements such as transmission lines, cavity resonators, etc., is required by the fact that the available techniques of network analysis and synthesis are limited to lumped-element systems. Such a limitation, however, is not so serious as it may appear at first because, in many practical cases, the results obtained in the case of lumped-element networks can be extended, in an approximate fashion, to the case of distributed-constant systems. For instance, such a technique has been successfully employed by the author in the design of microwave filters (1).[3]

An additional remark must be made on the fact that the coupling network is assumed to be lossless. In practice, of course, a certain amount of incidental dissipation will be present, which will result in a distortion of the characteristics of the coupling network. Techniques for computing this distortion and correcting for it have been developed in connection with the design of filters (2, 3). It seems appropriate, therefore, to neglect the presence of losses in the following analysis, and to rely on the available techniques for any correction that might become necessary in the final stage of a particular design.

Matching networks have been designed in the past following a step by step procedure leading to a ladder structure of reactances. Such a procedure has two main weaknesses. In the first place the designer does not know whether the requirements that he is trying to meet are consistent with the given load impedance. In the second place, it is implicitly assumed that a process based on successive improvements converges to the optimum design, or, at least, to a design reasonably close to the optimum. This is not the case, in general. An improved procedure of the same type, suggested by Bode (4, 5) in 1930 suffers still from most of the same weaknesses.

The first step toward a systematic investigation of matching networks was made by Bode (6) some time later, in connection with a very special but important type of load impedance. He considered the case of an impedance consisting of a resistance R shunted by a capacitance

[3] The boldface numbers in parentheses refer to the references appended to this paper.

C, and showed that the fundamental limitation on the matching network takes the form

$$\int_0^\infty \ln \frac{1}{|\rho|}\, d\omega \leq \frac{\pi}{RC}, \tag{3}$$

where ρ is the input reflection coefficient corresponding to the impedance Z in Fig. 1. If $|\rho|$ is kept constant and equal to $|\rho|_{max}$ over a frequency band of width w (in rad. per sec.), and is made equal to unity over the rest of the frequency spectrum, Eq. 3 yields

$$w \ln \frac{1}{|\rho|_{max}} \leq \frac{\pi}{RC}. \tag{4}$$

In words, the product of the bandwidth by the minimum pass-band value of $\ln 1/|\rho|_{max}$, has a maximum limit fixed by the product RC. Equation 3 indicates also that approaching a perfect match, that is, making $|\rho|$ very small at any frequency, results in an unnecessary waste of the area represented by the integral, and, therefore, in a reduction of the bandwidth. It is also clear that the limitation found by Bode applies to any impedance consisting of a reactive two-terminal-pair network terminated in a parallel RC combination. In this case, however, it is to be expected that additional, and possibly more stringent, limitations would be imposed by the reactive network. These additional limitations were not investigated by Bode.

The above discussion indicates the existence of definite limitations on the broadband matching of any given load impedance. These limitations must originate from some conditions of physical realizability of the function ρ representing the input reflection coefficient, conditions which must, in their turn, depend on the load impedance. For the purpose of discussion, one can then divide the matching problem in three parts as follows.

1. Given an impedance function Z_L, subject only to the restriction of being realizable by means of a finite number of lumped elements, find the conditions of physical realizability for the reflection-coefficient function ρ of a reactive two-terminal-pair network terminated in Z_L.
2. From the conditions of physical realizability for ρ, determine the minimum tolerance on the magnitude of the reflection coefficient over a prescribed frequency band.
3. Obtain appropriate functions for ρ which satisfy the conditions of physical realizability and, at the same time, lead to a matching network requiring a finite number of elements.

2. PHYSICAL REALIZABILITY

Darlington has shown (3) that any physically realizable impedance function can be considered as the input impedance of a reactive two-

terminal-pair network terminated in a pure resistance. This resistance can be made equal to one ohm in all cases by incorporating an appropriate ideal transformer in the reactive network. The network shown in Fig. 1 can then be transformed as indicated in Fig. 2.

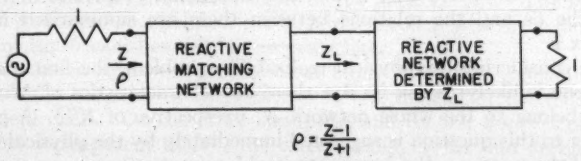

FIG. 2. Matching of an arbitrary load impedance.

At this point the problem under consideration takes a form particularly interesting from a general network-theory point of view. It can be shown that the over-all characteristics of a two-terminal-pair reactive network are completely specified, apart from an all-pass network in cascade, by the input impedance (or the reflection coefficient) measured at one pair of terminals when a one-ohm resistance is connected to the other pair of terminals. It follows that the conditions of physical realizability for ρ (see Fig. 2) are the same as the conditions that must be satisfied by any other function or set of functions representing the over-all characteristics of the two reactive networks of Fig. 2 in cascade. In conclusion the problem can be restated as follows:

Given two reactive two-terminal-pair networks of which one is fixed, the other arbitrary, determine the conditions of physical realizability for the over-all characteristics of the two networks connected in cascade.

In studying this problem it is convenient to turn the network of Fig. 2 end to end, as indicated in Fig. 3, so that the network resulting

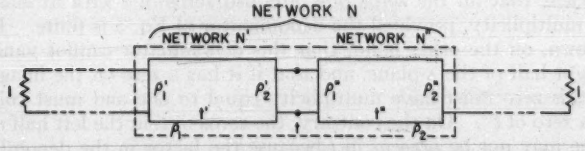

FIG. 3. Two reactive networks in cascade.

from the Darlington representation of the load impedance becomes the network N', and the matching network to be determined becomes N''. The reflection coefficients ρ_1 and ρ_2 refer to the whole network N terminated on both sides in one-ohm resistances. The transmission coefficient t of N is defined as the ratio of the voltage of the transmitted wave to the voltage of the incident wave with one-ohm terminations. The primed and double-primed symbols refer to the networks N' and

N'', respectively, and represent the reflection and transmission coefficients of these two networks when they are separately terminated in one-ohm resistances. These coefficients are functions of the real frequency ω, and more precisely, are analytic functions of the complex frequency variable $\lambda = \sigma + j\omega$. The functional properties of the ρ's and the t's and the relations between them are summarized in Appendix I.

In considering the physical realizability problem, the first question that one is likely to ask is: Are there any characteristics of N' which must belong to the whole network N, irrespective of N''? A partial answer to this question is suggested immediately by the physical structure of the system. If t' is zero at a real frequency, that is, at any point of the imaginary axis of the λ-plane, then a wave of that frequency traveling from left to right would be completely stopped by N', so that no part of the wave would come out of N'' or even enter it. It follows that any point of the imaginary axis which is a zero of the transmission coefficient t' must necessarily be a zero of transmission for the whole network N, and, therefore, must be a zero of t. Furthermore, the reflected wave at the input terminals cannot depend on N'' if no part of the incident wave reaches N''. Therefore, ρ_1 must be equal to ρ_1' for any value of $\lambda = j\omega$ for which t' is zero.

It is clear at this point that one should investigate carefully the effects on ρ_1 and t of the presence in t' of a zero of arbitrary multiplicity located at any point of the complex λ-plane. The starting point for such an investigation is provided by the two equations

$$t = \frac{t't''}{1 - \rho_2'\rho_1''}, \tag{5}$$

$$\rho_1 = \rho_1' + \rho_1'' \frac{(t')^2}{1 - \rho_2'\rho_1''}. \tag{6}$$

It is clear that all the zeros of t' are also zeros of t with at least the same multiplicity, provided the denominator of Eq. 5 is finite. It can be shown, on the other hand, that this denominator cannot vanish in the right half of the λ-plane, and that if it has a zero on the imaginary axis, this zero must have multiplicity equal to one and must coincide with a zero of t''. On the contrary, the zeros of t' in the left half of the λ-plane may not be present in t because the factor in the denominator can have zeros of arbitrary multiplicity in that part of the plane. It must be noted, however, in this regard, that if t' has a zero in the left half-plane, it must also have a zero symmetrically located in the right half-plane (see Appendix I), which must be present in t. Therefore the elimination of a zero in the left half-plane is, in a certain sense, only apparent. In conclusion, if t' has a zero in the right half-plane or on the imaginary axis, t must have the same zero with at least the same multiplicity.

With regard to the behavior of the reflection coefficient ρ_1 at any point in the right half-plane or on the imaginary axis, at which t has a zero of multiplicity n, Eq. 6 indicates that ρ_1 and its first $2n - 1$ derivatives are equal, respectively, to ρ_1' and its corresponding derivatives, and therefore are independent of the network N''. The special case of a zero of t at a point of the imaginary axis at which the denominator of Eq. 6 vanishes will be discussed later.

For reasons that will become clear later, it is more convenient to consider the behavior of the function $\ln 1/\rho_1$ instead of the reflection coefficient itself. On the other hand, if ρ_1 and its first $2n - 1$ derivatives are independent of N'', the corresponding value and derivatives of $\ln 1/\rho_1$ are also independent of N''. It follows that the first $2n$ coefficients of the Taylor series for $\ln 1/\rho_1$ about a zero of t' of multiplicity n in the right half-plane or on the imaginary axis will be independent of N''. In addition these coefficients are simply related to the locations of the zeros and poles of ρ_1, as indicated below.

In the particular case of a zero of t' at the origin, one has

$$\ln \frac{1}{\rho_1} = j\beta + A_1^0\lambda + A_3^0\lambda^3 + \cdots + A_{2n-3}^0\lambda^{2n-3} + A_{2n-1}^0\lambda^{2n-1} + \cdots, \quad (7)$$

where β is equal to zero or π, depending on the sign of ρ_1. The coefficients of this series are all real because on the imaginary axis the magnitude of ρ_1 is an even function of ω and the phase is an odd function of ω. In addition the even coefficients up to and including $A_{2(n-1)}$ vanish because of the zero of t of multiplicity n at the origin. The odd coefficients are given by

$$A_{2k+1}^0 = \frac{1}{2k+1}\left(\sum_i \lambda_{oi}^{-(2k+1)} - \sum_i \lambda_{pi}^{-(2k+1)}\right) \quad (8)$$

where the λ_{oi} and the λ_{pi} are, respectively, the zeros and the poles of ρ_1. For a zero of t' at infinity one obtains similarly

$$\ln \frac{1}{\rho_1} = j\beta + A_1^\infty\lambda^{-1} + A_3^\infty\lambda^{-3} + \cdots + A_{2n-3}^\infty\lambda^{-(2n-3)} + A_{2n-1}^\infty\lambda^{-(2n-1)} + \cdots, \quad (9)$$

where

$$A_{2k+1}^\infty = \frac{1}{2k+1}\left(\sum_i \lambda_{oi}^{2k+1} - \sum_i \lambda_{pi}^{2k+1}\right). \quad (10)$$

In the case of a zero of t' at a point ω_r of the imaginary axis, the even coefficients are real and the odd coefficients are imaginary up to and including the order $2n - 1$. One has then

$$\ln \frac{1}{\rho_1} = jB_0^{\omega_r} + A_1^{\omega_r}(\lambda - j\omega_r) + jB_2^{\omega_r}(\lambda - j\omega_r)^2 + A_3^{\omega_r}(\lambda - j\omega_r)^3 + \cdots + jB_{2n-2}^{\omega_r}(\lambda - j\omega_r)^{2n-2} + A_{2n-1}^{\omega_r}(\lambda - j\omega_r)^{2n-1} + \cdots, \quad (11)$$

where

$$\left(\ln \frac{1}{\rho_1}\right)_{\lambda=j\omega_r} = jB_0^{\omega_r}, \tag{12}$$

$$\frac{1}{k}\left[\sum_i (\lambda_{oi} - j\omega_r)^{-k} - \sum_i (\lambda_{pi} - j\omega_r)^{-k}\right] = \begin{cases} jB_k^{\omega_r} & \text{for } k \text{ even} \leq 2n-2, \\ A_k^{\omega_r} & \text{for } k \text{ odd} \leq 2n-1. \end{cases} \tag{13}$$

It is, of course, understood that if t' has a zero at a point $j\omega_r$ it must also have a conjugate zero at $-j\omega_r$. The coefficients of the series about the point $-j\omega_r$ are the conjugates of the coefficients of the series (11).

In considering the case of a zero of t' at a point σ_r of the positive real axis, one must remember that the reflection coefficient ρ_1 may have a zero of multiplicity n_0 at that point, in which case it must also have a pole of the same multiplicity at the symmetrical point $-\sigma_r$. Since the function $\ln 1/\rho_1$ is then singular at the point σ_r, one considers in its place the function

$$\ln\left\{\frac{1}{\rho_1}\left(\frac{\lambda-\sigma_r}{\lambda+\sigma_r}\right)^{n_0}\right\}, \tag{14}$$

from which the two singularities have been removed. Following the same line of thought as in the case of $\ln 1/\rho_1$, one can show without difficulty that the value of the new function (14) and its first $(2n - n_0 - 1)$ derivatives at the point σ_r are independent of N''. Using the Taylor series for this function, $\ln 1/\rho_1$ can be written finally in the form

$$\ln\frac{1}{\rho_1} = n_0 \ln\frac{\lambda+\sigma_r}{\lambda-\sigma_r} + A_0^{\sigma_r} + j\beta + A_1^{\sigma_r}(\lambda-\sigma_r) + A_2^{\sigma_r}(\lambda-\sigma_r)^2 + \cdots + A_{2n-n_0-2}^{\sigma_r}(\lambda-\sigma_r)^{2n-n_0-2} + A_{2n-n_0-1}^{\sigma_r}(\lambda-\sigma_r)^{2n-n_0-1} + \cdots, \tag{15}$$

where

$$\left[\ln\left[\frac{1}{\rho_1}\left(\frac{\lambda-\sigma_r}{\lambda+\sigma_r}\right)^{n_0}\right]\right]_{\lambda=\sigma_r} = A_0^{\sigma_r} + j\beta, \tag{16}$$

$$A_k^{\sigma_r} = \frac{1}{k}\left[\sum_i (\lambda_{oi} - \sigma_r)^{-k} - \sum_i (\lambda_{pi} - \sigma_r)^{-k}\right]. \tag{17}$$

The zero at σ_r and the pole at $-\sigma_r$ must, of course, be excluded from the above summations. The case of a zero of t' at an arbitrary point λ_r of the right half-plane is treated in the same manner. One obtains in this case

$$\begin{aligned}\ln\frac{1}{\rho_1} = n_0 \ln\frac{(\lambda-\lambda_r)(\lambda-\bar{\lambda}_r)}{(\lambda+\lambda_r)(\lambda+\bar{\lambda}_r)} &+ (A_0^{\lambda_r} + jB_0^{\lambda_r}) \\ &+ (A_1^{\lambda_r} + jB_1^{\lambda_r})(\lambda-\lambda_r) + (A_2^{\lambda_r} + jB_2^{\lambda_r})(\lambda-\lambda_r)^2 \\ &+ \cdots + [A_{(2n-n_0-2)}^{\lambda_r} + jB_{(2n-n_0-2)}^{\lambda_r}](\lambda-\lambda_r)^{2n-n_0-2} \\ &+ [A_{(2n-n_0-1)}^{\lambda_r} + jB_{(2n-n_0-1)}^{\lambda_r}](\lambda-\lambda_r)^{2n-n_0-1} + \cdots,\end{aligned} \tag{18}$$

where

$$A_0^{\lambda_r} + jB_0^{\lambda_r} = \ln \left\{ \frac{1}{\rho_1} \left[\frac{(\lambda - \lambda_r)(\lambda - \bar{\lambda}_r)}{(\lambda + \lambda_r)(\lambda + \bar{\lambda}_r)} \right]^{n_0} \right\}_{\lambda = \lambda_r}, \tag{19}$$

$$A_k^{\lambda_r} + jB_k^{\lambda_r} = \frac{1}{k} \left[\sum_i (\lambda_{oi} - \lambda_r)^{-k} - \sum_i (\lambda_{pi} - \lambda_r)^{-k} \right]. \tag{20}$$

Also in this case the pair of zeros at λ_r and $\bar{\lambda}_r$ and the pair of poles at $-\lambda_r$ and $-\bar{\lambda}_r$ must be excluded from the above summations. The coefficients of the series about the zero of t' at $\bar{\lambda}_r$ are the conjugates of the coefficients of the series (18).

The coefficients of the series (7), (9), (11), (15), and (18) up to the order $2n - n_0 - 1$ included are completely fixed by the given network N', with the possible exception of the last coefficients, of order $2n - 1$, in the case of a zero of t' on the imaginary axis. Such an exception arises from the fact that the factor $1 - \rho_2'\rho_1''$, in Eqs. 5 and 6, may have a zero of multiplicity one coinciding with a zero of t' on the imaginary axis. This situation leads to what may be called a degenerate case, because t'' must have then a zero at the same point which effectively combines with the zero of t'. In fact, the resulting multiplicity of the zero of the over-all transmission coefficient t is, in this case, one less than the sum of the multiplicities of the zeros of t' and t'' at the same point, as indicated by Eq. 5. The impedances measured at the common terminals of N' and N'' in the two directions at this frequency must be pure reactances with equal magnitudes and opposite signs.

Two simple examples of degenerate zeros are shown in Fig. 4 for the case of a zero at infinity (a), and a zero at $\lambda = \pm j\omega_r$ (b). It is clear in these examples that the zeros of transmission of N' and N'' will combine in such a way that the $(2n-1)^{th}$ derivative of ρ_1 will depend on N'' as well as on N' and therefore will not be equal to the corresponding derivatives of ρ_1'. Equation 6 shows that this is true in the general case of a degenerate zero of transmission. The examples of Fig. 4 indicate, however, that the change of the behavior of the input reflection coefficient when N'' is connected to N' must take place in a particular direction. For instance, in the case of Fig. 4(a), the fact that the total shunt capacitance $C_1 + C_2$ is larger than the capacitance in N' alone must somehow restrict the possible change of behavior. It can be shown[4] that, in the case of a zero of t' of multiplicity n on the imaginary axis, the coefficient A_{2n-1} of the Taylor series is always increased by the presence of N'' when n is odd, and is always decreased when n is even. The physical significance of this restriction and its practical importance will become clearer in the next section.

[4] For a proof of this and other similar statements, see the original Doctorate Thesis, available in the Library of the Massachusetts Institute of Technology.

The analysis carried out above has led to the formulation of a number of necessary conditions that must be satisfied by the functions representing the network N in order to be physically realizable by means of the given network N' and the arbitrary network N'' connected in cascade. These necessary conditions are summarized below for convenience. With reference to Fig. 3, all the zeros of t' which lie in the right half-plane or on the imaginary axis must appear as zeros of t with at least the same multiplicity. Moreover, a certain number of coefficients of the Taylor series for $\ln 1/\rho_1$ about each of the zeros of transmission must be equal to the corresponding coefficients for $\ln 1/\rho_1'$ or, in other words, must be independent of N''. The resulting number of real quantities independent of N'' is equal to the multiplicity of the

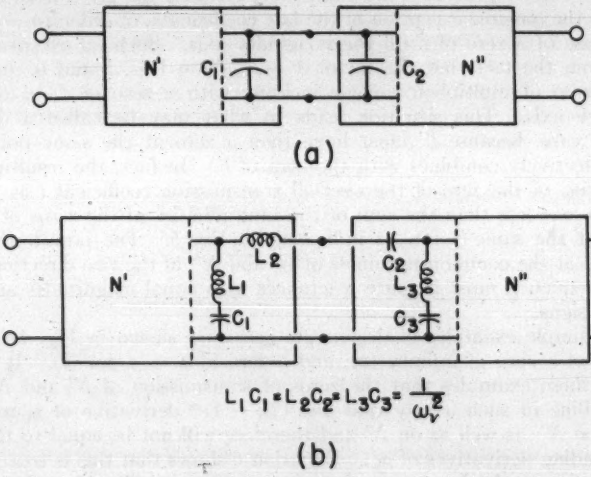

FIG. 4. Two examples of degenerate zeros of transmission.

corresponding zero of transmission in the case of a zero located at the origin or at infinity, to twice the multiplicity in the case of a pair of zeros on either the real or the imaginary axis, to four times the multiplicity in the case of a quadruplet of complex zeros. If a pair of zeros of t' at $-\lambda_r$ and $-\bar{\lambda}_r$ in the left half-plane is partially or totally eliminated by a pair of poles of t' of multiplicity n_0 located at the same points, a number $2n_0$ of these real quantities independent of N'' are missing. In this case, however, an equivalent number of conditions are imposed by the fact that ρ_1 must have a pair of poles of multiplicity n_0 at $-\lambda_r$ and $-\bar{\lambda}_r$, and, therefore, a pair of zeros with the same multiplicity at λ_r and $\bar{\lambda}_r$ (see Appendix I). A similar situation arises in the case of the elimination of a zero of transmission at $-\sigma_r$ on the real

axis. The case of a degenerate zero on the imaginary axis does not lead to any special difficulty.

Darlington (3) has shown that any two-terminal-pair reactive network can be constructed as a chain of sections each representing a simple zero of transmission, a pair of zeros, or a quadruplet of zeros; zeros of multiplicity n are represented by n similar sections. The order in which the sections are connected is immaterial, as far as the physical realizability of the network is concerned. Each section involves a number of elements equal to the number of zeros represented by the section plus the number of real quantities necessary to specify the location of the zeros. The resulting network is shown to require a minimum number of elements.

It is clear at this point that the number of necessary conditions imposed on ρ_1 and t by N' is equal to the number of independent parameters by which N' is completely specified. On the other hand, the conditions imposed by N' are independent of one another; it can be shown, in fact, by interchanging the sections forming N' that any one of these conditions can be changed without disturbing the others. To prove that these conditions of physical realizability are sufficient as well as necessary one needs only to observe, in addition, that the network N defined by ρ_1 and t can be constructed in two parts, the first of which contains all the sections representing the zeros of t'. If the correct sign of ρ_1 is used (the sign differentiates the desired network from its reciprocal), this first part with an appropriate ideal transformer at the output terminals, can be identified with the given network N', because all the sections contained in it are completely specified by the conditions of physical realizability imposed on ρ_1, which, on the other hand, completely specify N'. The second part of the network is certainly realizable because it can be obtained by simply completing the synthesis procedure developed by Darlington.

The above analysis has led thus to the determination of necessary and sufficient conditions for the physical realizability of the reflection coefficient ρ_1 when ρ_1' and t' are specified. In a practical matching problem, however, ρ_1' and t_1' are given indirectly through ρ_2', which, in turn, is specified by the load impedance Z_L. On the other hand, ρ_1' and t' are completely specified by ρ_2', apart from an arbitrary all-pass network connected to terminals 1 of N'. This arbitrary network, however, can be neglected because it does not produce any reflection by itself nor does it change the phase of any other reflection when the network N' is driven from terminals 2. Therefore, for the purposes of this discussion, N' is completely specified by Z_L. On the other hand, one can observe that the reflection coefficient which is measured in an actual matching problem is not ρ_1 but ρ_2, since the source is connected to terminals (2) of N. This fact, however, is immaterial since only the magnitude of ρ_2 is of importance in most cases and $|\rho_2| = |\rho_1|$

for $\lambda = j\omega$. Moreover, if one were interested in the whole function ρ_2, it would be a simple matter to express the conditions of physical realizability in terms of the zeros and poles of ρ_2, since they are simply related to the corresponding singularities of ρ_1 (see Appendix I).

3. LIMITATIONS ON THE TOLERANCE AND THE BANDWIDTH

The next step in the solution of the matching problem is the transformation of the conditions of physical realizability derived above into a set of relations suitable for the determination of the theoretical limitations on the bandwidth and tolerance of match. Such relations must involve the behavior of the magnitude of the reflection coefficient on the

TABLE I.—*Integral Relations Obtained from the Conditions of Physical Realizability*

Zero of t'	Frequency Variable	Integral Relation
origin	ω	$\int_0^\infty \omega^{-2(k+1)} \ln(1/\lvert\rho_1\rvert)\, d\omega = (-1)^k \frac{\pi}{2} F_{2k+1}^0$
infinity	ω	$\int_0^\infty \omega^{2k} \ln(1/\lvert\rho_1\rvert)\, d\omega = (-1)^k \frac{\omega}{2} F_{2k+1}^\infty$
$\pm j\omega_\nu$	$x = \omega/\omega_\nu$	$\int_0^\infty g_{2k}^{\omega_\nu} \ln(1/\lvert\rho_1\rvert)\, dx = (-1)^{k+1} \frac{\pi}{2} \omega_\nu^{2k} G_{2k}^{\omega_\nu}$ $\int_0^\infty f_{2k+1}^{\omega_\nu} \ln(1/\lvert\rho_1\rvert)\, dx = (-1)^k \frac{\pi}{2} \omega_\nu^{2k+1} F_{2k+1}^{\omega_\nu}$
$\pm \sigma_\nu$	$x = \omega/\lvert\sigma_\nu\rvert$	$\int_0^\infty f_k^{\sigma_\nu} \ln(1/\lvert\rho_1\rvert)\, dx = (-1)^k \frac{\pi}{2} \sigma_\nu^k F_k^{\sigma_\nu}$
$\pm \sigma_\nu \pm j\omega_\nu$	$x = \omega/\lvert\lambda_\nu\rvert$	$\int_0^\infty f_{2k}^{\lambda_\nu} \ln(1/\lvert\rho_1\rvert)\, dx = (-1)^k \frac{\pi}{2} \lvert\lambda_\nu\rvert^{2k} F_{2k}^{\lambda_\nu}$ $\int_0^\infty g_{2k}^{\lambda_\nu} \ln(1/\lvert\rho_1\rvert)\, dx = (-1)^{k+1} \frac{\pi}{2} \lvert\lambda_\nu\rvert^{2k} G_{2k}^{\lambda_\nu}$ $\int_0^\infty f_{2k+1}^{\lambda_\nu} \ln(1/\lvert\rho_1\rvert)\, dx = (-1)^k \frac{\pi}{2} \lvert\lambda_\nu\rvert^{2k+1} F_{2k+1}^{\lambda_\nu}$ $\int_0^\infty g_{2k+1}^{\lambda_\nu} \ln(1/\lvert\rho_1\rvert)\, dx = (-1)^k \frac{\pi}{2} \lvert\lambda_\nu\rvert^{2k+1} G_{2k+1}^{\lambda_\nu}$

imaginary axis, that is at real frequencies, and the coefficients of the Taylor series which are fixed by the given load impedance.

Cauchy's integral relations provide the appropriate tool for the desired transformation. The function $\ln 1/\rho$ is multiplied first by a function having poles of appropriate multiplicity at the zero, pair, or quadruplet of zeros of t' under consideration and is integrated then over the contour formed by the imaginary axis and the semicircle at infinity in the right half-plane; appropriate indentations must be provided when the poles are located on the imaginary axis. If ρ_1 has zeros in the right half-plane, it is more convenient to use instead of ρ_1 the function ρ_0 obtained from ρ_1 by moving all the zeros in the right half-plane to symmetrical positions in the left half-plane. This new function

ρ_0 has the same magnitude as ρ_1 on the imaginary axis. It is also convenient to make ρ_0 positive at the origin by changing its sign if necessary. The coefficients F and G of the Taylor series for $\ln 1/\rho_0$ corre-

TABLE II.—*The Coefficients Appearing in the Integral Relations of Table I*

$$F^{0}_{2k+1} = A^{0}_{2k+1} - \frac{2}{2k+1}\sum_i \lambda_{ri}^{-(2k+1)}$$

$$F^{\infty}_{2k+1} = A^{\infty}_{2k+1} - \frac{2}{2k+1}\sum_i \lambda_{ri}^{2k+1}$$

$$G^{\omega_\nu}_{0} = B^{\omega_\nu}_{0} + j\left[\sum_i \ln\frac{-\bar{\lambda}_{ri} - j\omega_\nu}{\lambda_{ri} - j\omega_\nu}\right] + \beta$$

$$F^{\omega_\nu}_{2k+1} = A^{\omega_\nu}_{2k+1} - \frac{2}{2k+1}\,Re\sum_i (\lambda_{ri} - j\omega_\nu)^{-(2k+1)}$$

$$G^{\omega_\nu}_{2k} = B^{\omega_\nu}_{2k} - \frac{1}{k}\,Im\sum_i (\lambda_{ri} - j\omega_\nu)^{-2k}$$

$$F^{\sigma_\nu}_{0} = A^{\sigma_\nu}_{0} - Re\sum_i \frac{-\bar{\lambda}_{ri} - \sigma_\nu}{\lambda_{ri} - \sigma_\nu}$$

$$F^{\sigma_\nu}_{k} = A^{\sigma_\nu}_{k} - \frac{1}{k}\left[\sum_i (\lambda_{ri} - \sigma_\nu)^{-k} - \sum_i (-\lambda_{ri} - \sigma_\nu)^{-k}\right]$$

$$F^{\lambda_\nu}_{0} + jG^{\lambda_\nu}_{0} = A^{\lambda_\nu}_{0} + jB^{\lambda_\nu}_{0} - \sum_i \ln\frac{-\bar{\lambda}_{ri} - \lambda_\nu}{\lambda_{ri} - \lambda_\nu} + j\beta$$

$$F^{\lambda_\nu}_{k} + jG^{\lambda_\nu}_{k} = A^{\lambda_\nu}_{k} + jB^{\lambda_\nu}_{k} - \frac{1}{k}\left[\sum_i (\lambda_{ri} - \lambda_\nu)^{-k} - \sum_i (-\bar{\lambda}_{ri} - \lambda_\nu)^{-k}\right]$$

$$\beta = \begin{cases} 0 & \text{if } \rho_1(0) \text{ and } \rho_0(0) \text{ have the same sign} \\ \pi & \text{if } \rho_1(0) \text{ and } \rho_0(0) \text{ have opposite signs} \end{cases}$$

TABLE III.—*The Functions Appearing in the Integral Relations of Table I*

$$f^{\omega_\nu}_{2k+1} = \frac{(1+x)^{2(k+1)} + (1-x)^{2(k+1)}}{2(1-x^2)^{2(k+1)}}$$

$$g^{\omega_\nu}_{2k} = \frac{(1+x)^{2k+1} + (1-x)^{2k+1}}{2(1-x^2)^{2k+1}}$$

$$f^{\sigma_\nu}_{k} = \frac{(1+jx)^{k+1} + (1-jx)^{k+1}}{2(1+x^2)^{k+1}}$$

$$\left.\begin{matrix} f^{\lambda_\nu}_{2k} \\ g^{\lambda_\nu}_{2k} \end{matrix}\right\} = \begin{matrix} (-1)^k \\ (-1)^{k+1} \end{matrix}\Big\}\Big[\{[\delta + j(x + \sqrt{1-\delta^2})]^{-(2k+1)} - [-\delta + j(x - \sqrt{1-\delta^2})]^{-(2k+1)}\}$$

$$+ \begin{Bmatrix} + \\ - \end{Bmatrix}\{[\delta + j(x - \sqrt{1-\delta^2})]^{-(2k+1)} - [-\delta + j(x + \sqrt{1-\delta^2})]^{-(2k+1)}\}\Big]$$

$$\left.\begin{matrix} f^{\lambda_\nu}_{2k+1} \\ g^{\lambda_\nu}_{2k+1} \end{matrix}\right\} = (-1)^k\Big[\{[\delta + j(x + \sqrt{1-\delta^2})]^{-2(k+1)} + [-\delta + j(x - \sqrt{1-\delta^2})]^{-2(k+1)}\}$$

$$+ \begin{Bmatrix} + \\ - \end{Bmatrix}\{[\delta + j(x - \sqrt{1-\delta^2})]^{-2(k+1)} + [-\delta + j(x + \sqrt{1-\delta^2})]^{-2(k+1)}\}\Big]$$

$$\delta = \frac{\sigma_\nu}{|\lambda_\nu|}$$

sponding to the A's and B's for $\ln 1/\rho_1$ are given in Table II. The integral relations obtained by following this procedure are collected in Table I and the weighting functions f and g, which are part of the integrand are tabulated in Table III. The λ_{ri} appearing in Table II are the zeros of ρ_1 that lie in the right half-plane.

The integral relations of Table I are the crux of the paper because they express the conditions of physical realizability in terms of the observable behavior of a physical quantity, namely the behavior, over the frequency spectrum, of the magnitude of the reflection coefficient. To obtain the optimum tolerance of match, one must determine then the function $|\rho_1|$ which is a solution of the set of equations formed by these integral relations and whose maximum deviation from zero over a prescribed frequency band is a minimum. This problem was solved only in very special cases; however, the relations of Table I yield directly useful information on the nature of the theoretical limitations on the tolerance and bandwidth of match, as indicated below.

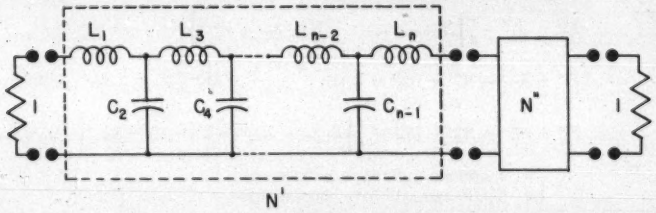

FIG. 5. Network N' with n zeros of transmission at infinity, and matching network N''.

The special case of a network N' having all the zeros of transmission at infinity will be considered first. Such a network can be realized in either the form of a low-pass ladder structure of the type shown in Fig. 5, or in the dual form (starting with a shunt capacitance). In this former case the coefficient A_1 depends on L_1 alone, A_3 depends on L_1 and C_2, A_5 depends on L_1, C_2, and L_3, and so forth, since each of the elements represents a zero of transmission at infinity. The integral relations which apply to the case of a zero of transmission at infinity of multiplicity equal to 3 are rewritten below for convenience.

$$\int_0^\infty \ln \frac{1}{|\rho_1|}\, d\omega = \frac{\pi}{2}\left(A_1^\infty - 2\sum_i \lambda_{ri}\right), \tag{21}$$

$$\int_0^\infty \omega^2 \ln \frac{1}{|\rho_1|}\, d\omega = -\frac{\pi}{2}\left(A_3^\infty - \frac{2}{3}\sum_i \lambda_{ri}^3\right), \tag{22}$$

$$\int_0^\infty \omega^4 \ln \frac{1}{|\rho_1|}\, d\omega = \frac{\pi}{2}\left(A_5^\infty - \frac{2}{5}\sum_i \lambda_{ri}^5\right). \tag{23}$$

The λ_{ri} are the zeros of ρ_1 that lie in the right half-plane.

The left-hand side of the first equation represents the area under the curve $\ln 1/|\rho_1|$ *versus* frequency. The coefficient A_1^∞ is fixed by the first element L_1 of the network N', while the λ_{ri} are arbitrary quantities subject only to two restrictions; namely, that their real parts must be positive and that they must appear in conjugate pairs if they are complex. It follows that the summation in Eq. 21 is always real and positive so that A_1^∞ sets an upper limit to the area represented by the integral. It is clear that the best possible utilization of this area is obtained when $\ln 1/|\rho_1|$ is kept constant over the desired frequency band and is made equal to zero over the rest of the frequency spectrum. This situation is illustrated for the low-pass case in Fig. 6. If w is the

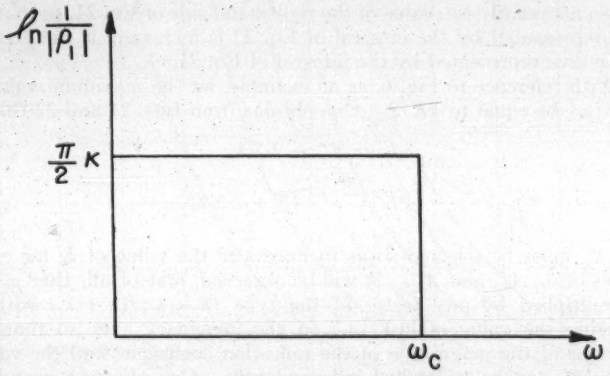

FIG. 6. Optimum frequency response.

desired bandwidth ($w = \omega_c$ in Fig. 6) the best possible tolerance is given by

$$\left[\ln \frac{1}{|\rho_1|}\right]_{\max} = \frac{\pi}{2w} A_1^\infty. \tag{24}$$

This theoretical limitation was first found by Bode, as pointed out above. In fact, when the load consists of a parallel RC combination, the coefficient A_1^∞ becomes equal to $2/RC$. Bode, however, did not consider the case of a network N' consisting of more than one element. In this case a number of equations equal to the number of elements in N' will have to be satisfied simultaneously. Suppose, for instance, that N' contains two elements, L_1 and C_2; that is, N' has a zero of transmission of multiplicity equal to two, so that Eqs. 21 and 22 must be satisfied simultaneously. If the rectangular function which yields the optimum tolerance according to Eq. 24 is used in Eq. 22, the value of the integral may be larger or smaller than $-\pi A_3^\infty/2$ (A_3^∞ is in general

negative). If it is smaller, it is a simple matter to reduce the magnitude of the right-hand side of Eq. 22. In fact, it was pointed out before that in the case of a degenerate zero of transmission, the algebraic value of A_3^∞ can be increased; that is, its absolute value can be decreased. Physically this operation amounts to starting the matching network N'' with a shunt capacitance which has the effect of increasing the value of the capacitance C_2 in N'. If on the contrary the value of the integral in Eq. 22 is larger than $-\pi A_3^\infty/2$, the optimum tolerance given by Eq. 24 cannot be reached. One observes then that the value of the summation in Eq. 22 can be either positive or negative, so that the value of the right-hand side of Eq. 22 can be increased by introducing appropriate zeros of ρ_1 in the right half of the plane. These zeros, however, reduce necessarily the value of the right-hand side of Eq. 21, so that the area represented by the integral of Eq. 22 is increased at the expense of the area represented by the integral of Eq. 21.

With reference to Fig. 6, as an example, let the maximum value of $\ln 1/|\rho_1|$ be equal to $\pi K/2$. One obtains from Eqs. 21 and 22 that

$$\omega_c K = A_1^\infty - 2 \sum_i \lambda_{ri}, \tag{25}$$

$$\omega_c^3 K = -3A_3^\infty + 2 \sum_i \lambda_{ri}^3. \tag{26}$$

The λ_{ri} must be selected so as to maximize the value of K for given values of ω_c, A_1^∞, and A_3^∞. It will be observed, first of all, that ρ_1 can be multiplied by any factor of the type $(\lambda - \lambda_r)/(\lambda + \lambda_r)$ without changing the value of $\ln 1/|\rho_1|$ on the imaginary axis, so that the behavior of the magnitude of the reflection coefficient and the values of the λ_{ri} can be controlled independently. One observes next that since the summation in Eq. 22 must be made positive, both equations can be satisfied by using a single zero $\lambda_r = \sigma_r$ located on the positive real axis. On the other hand, maximizing K is equivalent to making $\sum_i \lambda_{ri}^3$ as large as possible while keeping $\sum_i \lambda_{ri}$ as small as possible. Moreover, if $Re\, \lambda_{ri}^3 > 0$, then $Re\, \lambda_{ri}^3 \leq \sigma_{ri}^3$, and $\sum_i Re\, \lambda_{ri}^3 \leq (\sum_i \sigma_{ri})^3$. It follows that the maximum value of K is obtained by using a single zero located at σ_r. Equations 25 and 26 then become

$$\omega_c K = A_1^\infty - 2\sigma_r, \tag{27}$$

$$\omega_c^3 K = -3A_3^\infty + 2\sigma_r^3. \tag{28}$$

Solving these two equations by eliminating σ_r yields the maximum theoretical value of K as a function of the cut-off frequency ω_c. The maximum pass-band value of $\ln 1/|\rho_1|$ is plotted in Fig. 7 as a function of ω_c/A_1^∞ for different values of the parameter $-A_3^\infty/(A_1^\infty)^3$. The curve $K = A_1^\infty/\omega_c$ forms the boundary of the region in which the

optimum design is obtained by simply increasing the value of the second element.

When the network N' consists of three or more elements, the problem of determining the optimum tolerance of match becomes much more difficult, and no general solution has been obtained. However, a few general considerations can be made. In the first place, the rectangular form of frequency behavior for $\ln 1/|\rho_1|$ yields the optimum tolerance in all cases, because it provides the best utilization of the areas represented by the successive integrals. In the case of a passband extending

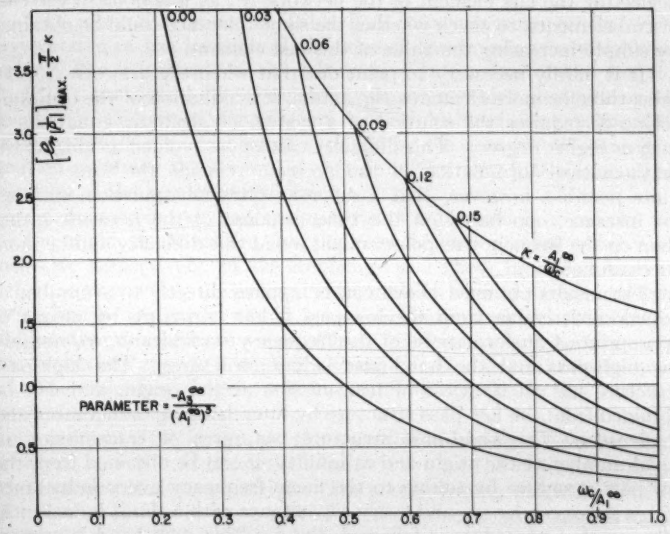

FIG. 7. Optimum tolerance of match for a C–L–R impedance.

from zero frequency to ω_c, the equations to be satisfied take the general form

$$\omega_c^{2k+1}K = (-1)^k\left[(2k+1)A_{2k+1}^\infty - 2\sum_i \lambda_{ri}^{2k+1}\right]. \tag{29}$$

In the last equation of the set $k = n + 1$, n being the number of elements in the network N'. It seems reasonable to expect that the number of λ_{ri} for which K is a maximum will be equal, in general, to the minimum number required for the solution of the set of equations. The reasoning followed in the case of two elements, however, could not be extended rigorously to the case of n elements. Moreover, the solution of such a system of equations might yield λ_{ri} with negative real parts which, of course, would not be acceptable. In this case

more λ_{ri} would have to be used, and their values would have to be determined by maximizing K.

The coefficient A_{2n-1} in the last equation of any particular set can be changed, but only in one direction, by combining one zero of transmission of N' with a similar zero of transmission of N'', as pointed out above. It will be observed that the direction in which A_{2n-1} can be changed corresponds always to a decrease of the area represented by the integral on the right side of the same equation. It follows that one must determine first the optimum tolerance that can be obtained by neglecting the last element of the network N', as was done in the case of two elements, to check whether the same tolerance could be obtained by simply increasing the value of this last element.

It is hardly necessary to point out that when the network N' contains three or more elements, the actual determination of the optimum tolerance requires the solution of a system of algebraic equations of fifth or higher degree. This difficulty cannot be avoided as long as the mathematical formulation of the problem remains the same. It is quite possible, however, that a different physical approach, such as, for instance, one based on the time response of the network rather than on the frequency response, might avoid this difficulty and be more successful.

The results obtained above can be applied directly to a number of networks derivable from the low-pass ladder structure by means of appropriate transformations of the frequency variables (7, 8), notably the high-pass and the band-pass ladder structures. The high-pass structure has all its zeros of transmission at the origin, and can be obtained from the low-pass structure by interchanging inductances and condensers. The band-pass structure has zeros of transmission in equal number at the origin and at infinity; it can be obtained from the low-pass structure by tuning to the mean frequency every inductance with a series condenser, and every capacitance with a shunt inductance. When such a procedure is followed, the resulting pass band is numerically equal to the cut-off frequency of the original low-pass structure.

An additional remark is in order with regard to networks with zeros of transmission at both the origin and infinity. If the multiplicity of the zero at the origin is n_0 and the multiplicity of the zero at infinity is n_∞, the conditions of physical realizability for the matching network will yield $n_0 + n_\infty$ equations of the types indicated in Table I. When a rectangular-shaped function is used for $\ln 1/|\rho_1|$, these equations take the forms

$$(\omega_2^{2k+1} - \omega_1^{2k+1})K = (-1)^k[(2k+1)A^{\infty}_{2k+1} - 2\sum_i \lambda_{ri}^{2k+1}], \quad (30)$$

$$(\omega_1^{-(2k+1)} - \omega_2^{-(2k+1)})K = (-1)^k[(2k+1)A^{0}_{2k+1} - 2\sum_i \lambda_{ri}^{-(2k+1)}], \quad (31)$$

where ω_1 and ω_2 are, respectively, the low-frequency and the high-frequency ends of the pass band and K is the pass-band value of $\ln 1/|\rho_1|$ divided by $\pi/2$. To determine the maximum value of K, one must solve simultaneously the whole set of equations. However, if $\omega_2 \gg \omega_1$ the two sets of equations relating to the two zeros of transmission can be solved separately. In other words, the high-frequency response of the network can be considered independently of the low-frequency response. The two sets of equations will yield different values of K for given ω_1 and ω_2, the smaller of which will represent the optimum tolerance of match.

The integral relations of Table I all have the same general form, irrespective of the location of the zero of transmission to which they refer. The integrand on the left-hand side consists of the function $\ln 1/|\rho_1|$ multiplied by a weighting function which depends on the location of the zero of transmission. The right-hand side consists of the difference between a coefficient specified by the network N' and a summation involving the zeros of ρ_1 that lie in the right half-plane and the location of the zero of transmission.

In the simple case concerning zeros of transmission at infinity and at the origin, the weighting functions are the even powers, positive and negative respectively, of the frequency ω. These functions have the effect of preventing the arbitrary distribution over the frequency spectrum of the area under the $\ln 1/|\rho_1|$-versus-frequency curve. In particular they prevent the value of $\ln 1/|\rho_1|$ from remaining large when the frequency approaches infinity in the one case and zero in the other.

The weighting functions have similar properties in the case of a zero of transmission on the imaginary axis. In the first place the area represented by the integral in the equation involving $A_1^{\omega_r}$ can be equal, at most, to $\pi A_1^{\omega_r}\omega_r/2$ because the summation on the right-hand side of the equation is always positive. The corresponding weighting function $f_1^{\omega_r}$, plotted in Fig. 8, has a sort of even symmetry with respect to the point $\omega = \omega_r$. This fact would indicate that the area represented by $A_1^{\omega_r}$ can be divided arbitrarily between the two sides of ω_r. Such an arbitrary division, however, is not possible because the weighting function $g_0^{\omega_r}$ (plotted in Fig. 8) in the first equation of the set has a sort of odd symmetry with respect to the same point ω_r. The division of the area is thus limited by the value of $B_0^{\omega_r}$ and by the fact that the use of any zero of ρ_1 in the right half-plane to modify $B_0^{\omega_r}$ results in a decrease of the area represented by the integral in the equation involving $A_1^{\omega_r}$. The weighting functions of higher order are, alternatively, of the even-symmetry and of the odd-symmetry types, and rise faster and faster with their order when ω approaches ω_r, as indicated in Fig. 8.

In the case of a zero of transmission on the real axis, the integral in the first equation can never be larger than $\pi A_0^{\omega_r}/2$ and, in addi-

tion, the integral in the second equation can never be smaller than $(-\pi\sigma_r A_1^{\sigma_r}/2)$. It will be noted in this regard that the weighting function $f_0^{\sigma_r}$ is positive for all values of ω, while the function $f_1^{\sigma_r}$ is positive

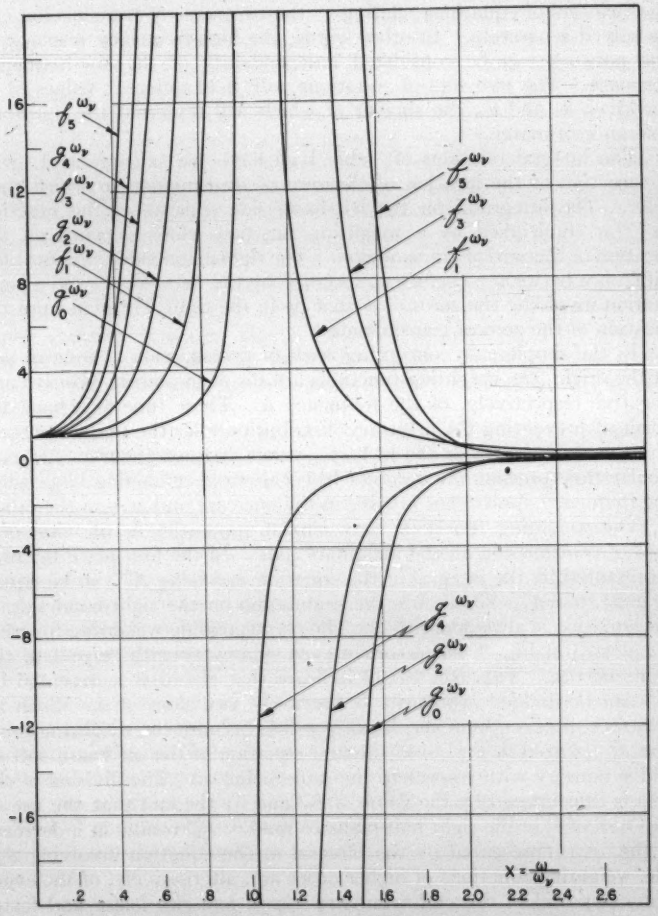

FIG. 8. Weighting functions for zeros of transmission at $\lambda_r = \pm j\omega_r$.

for $\omega < \sigma_r$ and negative for $\omega > \sigma_r$, as shown in Fig. 9. It follows that, roughly speaking, the value of $\ln 1/|\rho_1|$ is limited at low frequencies

by the first equation and at high frequencies by the second equation. If the multiplicity of the zero of transmission is larger than one, the areas represented by the integrals in these first two equations are pre-

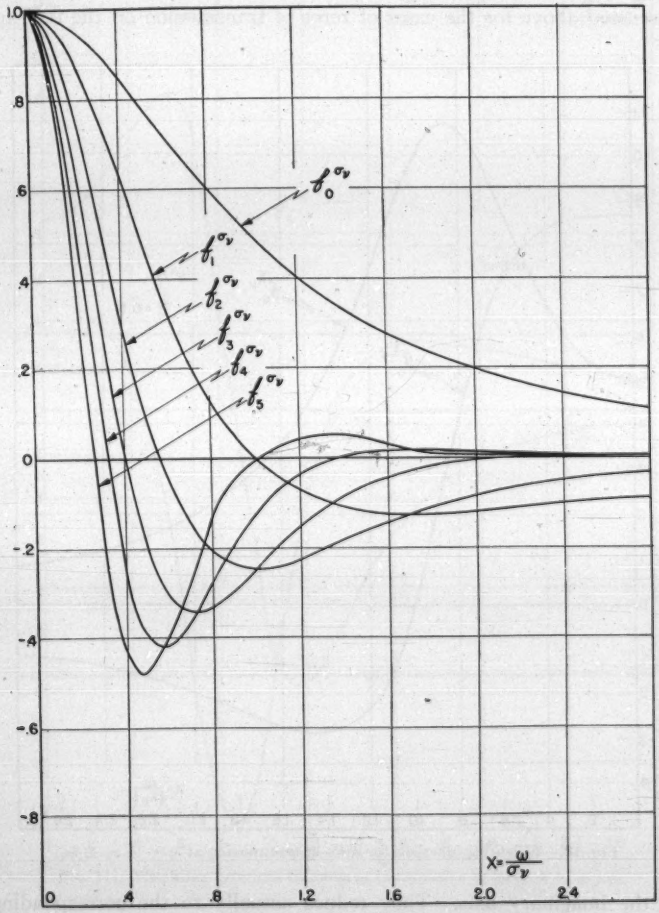

FIG. 9. Weighting functions for zeros of transmission at $\lambda_r = \pm \sigma_y$.

vented from being distributed arbitrarily over the frequency spectrum by equations of higher order. The first six weighting functions corre-

sponding to a zero of transmission of multiplicity equal to three are plotted in Fig. 9.

In the case of zeros of transmission at complex frequencies, the weighting functions f_k and g_k lead to limitations very similar to the ones discussed above for the cases of zeros of transmission on the real and

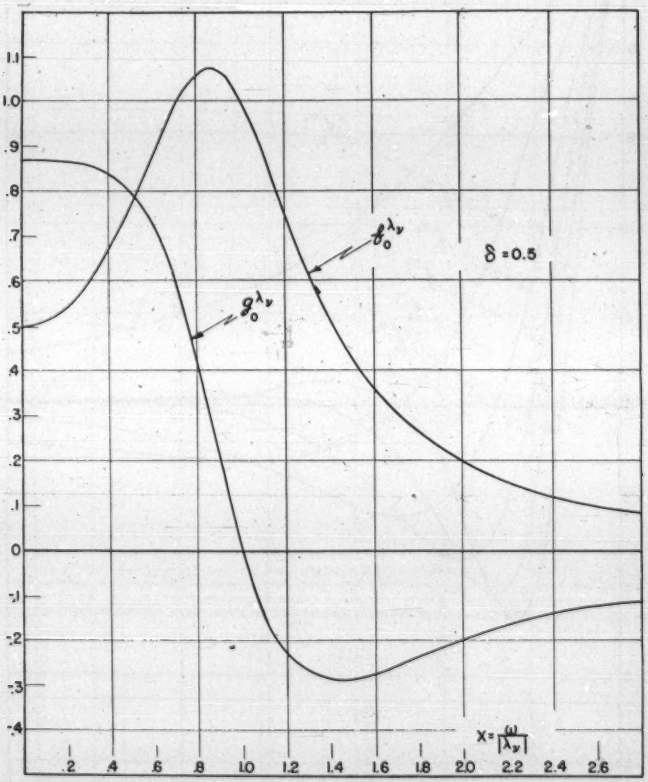

FIG. 10. Weighting functions for zeros of transmission at $\lambda_\nu = \pm\sigma_\nu \pm j\omega_\nu$.

on the imaginary axis. They reduce actually to the corresponding functions for these cases when the parameter $\delta = \sigma_\nu/|\lambda_\nu|$ approaches infinity and zero, respectively. The weighting functions of orders 0, 1, and 2 are plotted in Figs. 10 to 15 for δ equal to 0.5 and 0.05.

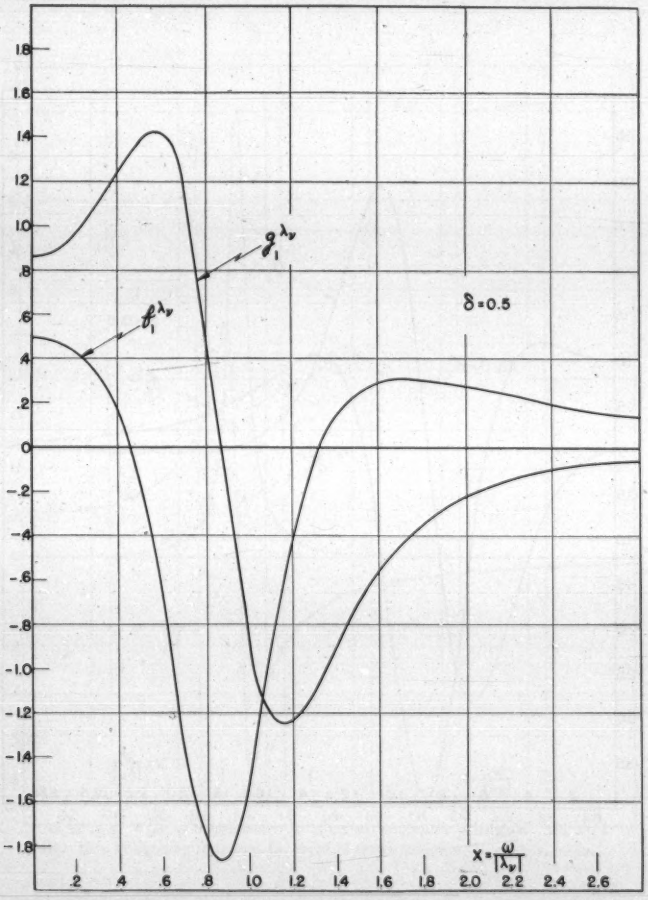

FIG. 11. Weighting functions for zeros of transmission at $\lambda_r = \pm \sigma_r \pm j\omega_r$.

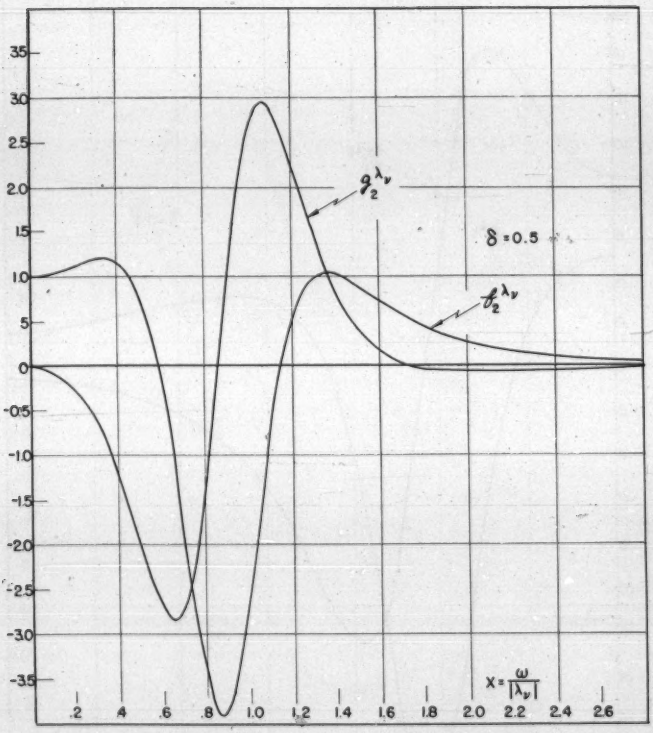

FIG. 12. Weighting functions for zeros of transmission at $\lambda_\nu = \pm \sigma_\nu \pm j\omega_\nu$.

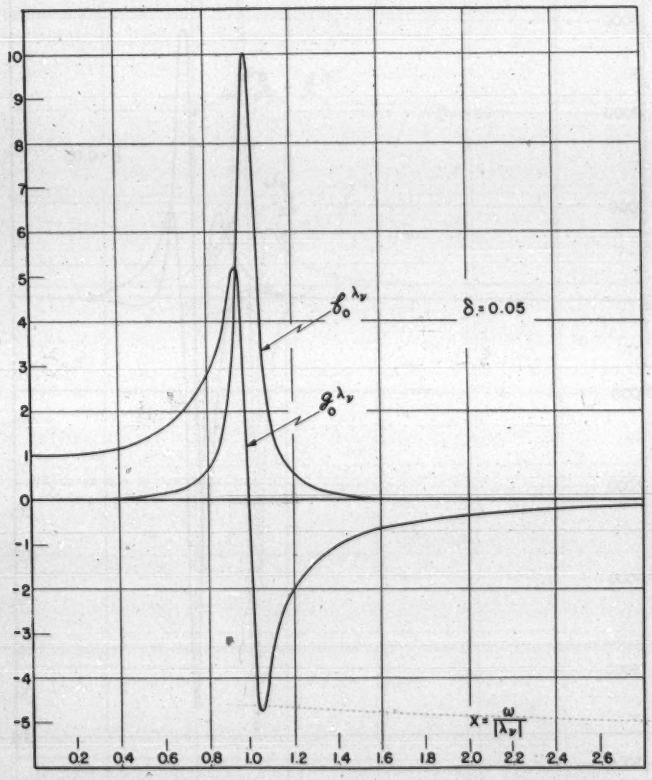

FIG. 13. Weighting functions for zeros of transmission at $\lambda_\nu = \pm \sigma_\nu \pm j\omega_\nu$.

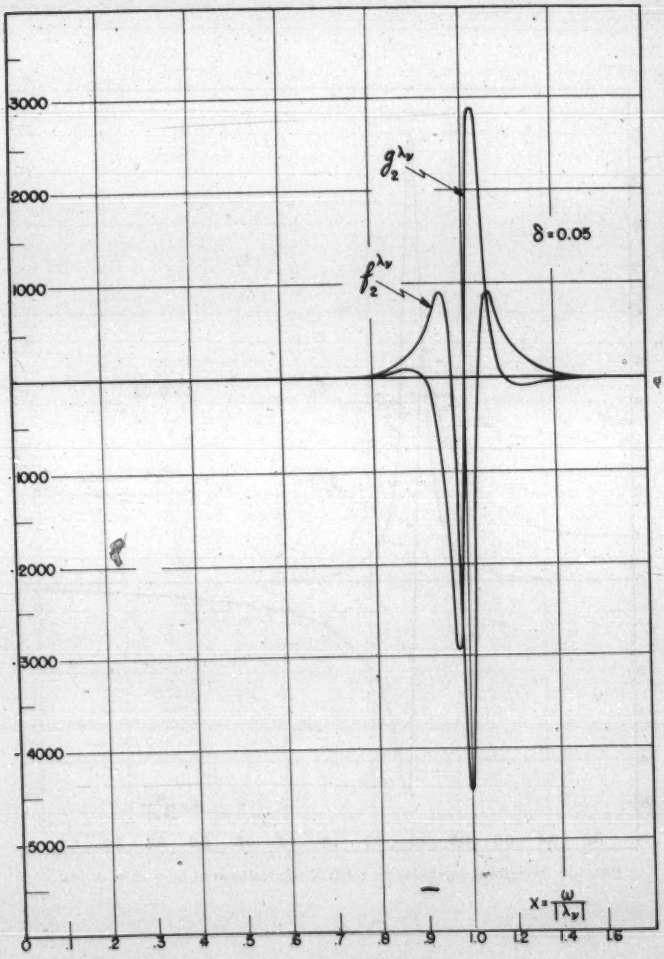

FIG. 14. Weighting functions for zeros of transmission at $\lambda_\nu = \pm\sigma_\nu \pm j\omega_\nu$.

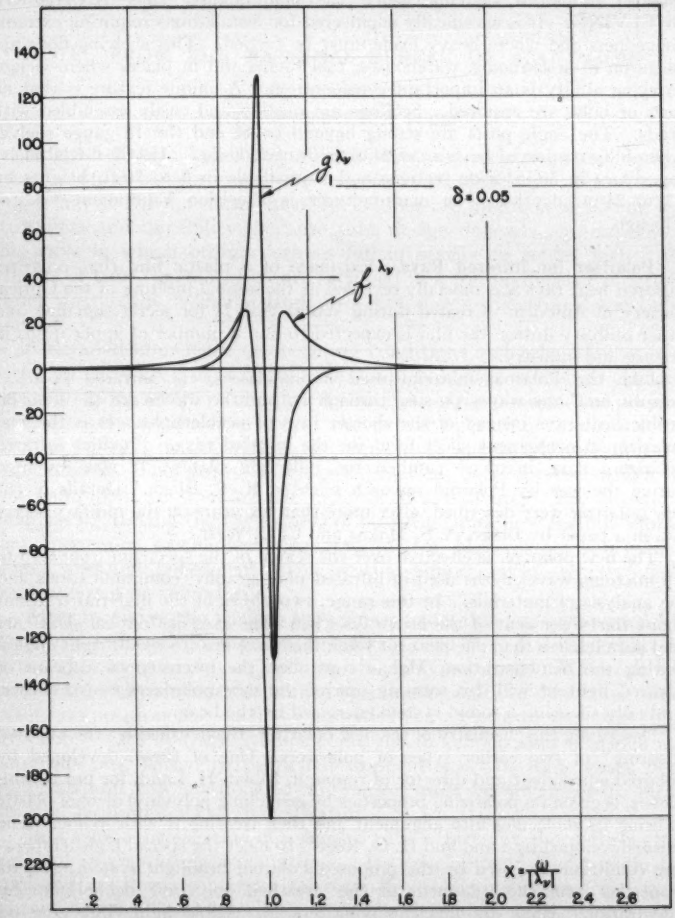

FIG. 15. Weighting functions for zeros of transmission at $\lambda_y = \pm \sigma_y \pm j\omega_y$.

To be concluded in the February issue.

Heavy Duty Shelving.—Production has recently been started on a type of all-steel industrial shelving which the manufacturer calls IRON-GRIP SHELVING. It is specifically engineered for installations requiring extreme ruggedness and where heavy loads must be carried. This shelving finds application in stockrooms, warehouses, tool rooms and in places where weight carrying ability is an important consideration. A unique feature is that no nuts or bolts are required. Sections are quickly and easily assembled with studs. The angle posts are strong beyond belief and the 18 gauge shelves when fully reinforced have a *weight capacity* of *2000 lbs.!* IRON-GRIP shelving comes in 36-in. wide sections and is available in 6 to 10-ft. heights by 12 to 24-in. depths. The manufacturer is Precision Equipment Co., of Chicago.

Polarizer for Infrared Rays.—Existence of a plastic film that polarizes infrared heat rays was officially revealed at the annual meeting of the Optical Society of America. Created during World War II for secret signaling and other military duties, the film is expected to find a number of applications in science and industry.

Like the Polaroid material used in sunglasses, the infrared polarizer "combs out" the waves passing through it, but the waves are the long invisible heat rays instead of the shorter rays of visible light. It is the first polarizer in convenient sheet form for the infrared rays. Previous infrared polarizers have involved cumbersome reflecting plates. It was invented during the war by Polaroid research scientist R. P. Blake. Details of the new polarizer were described, after more than six years on the military secret list, in a paper by Blake, A. S. Makas and C. D. West.

The new polarizer is effective over the region of the spectrum from 0.75 to 2.8 microns, wavelengths used in infrared photography, communications and the analysis of materials. In this range, two pieces of the material transmit about thirty per cent of the heat rays when their axes or "optical slots" are held parallel, less than one per cent when their axes are crossed at right angles. During the demonstration, Makas controlled the intensity of a beam of infrared light at will, by rotating one of the new polarizers over another, gradually silencing a sound system energized by the beam.

Describing the chemistry of the new polarizer, Blake called it "the talented offspring" of two earlier types of polarizers. One of these, developed by Polaroid's president and director of research, Edwin H. Land, for use in sunglasses, is given its polarizing properties by stretching polyvinyl alcohol plastic to bring its molecules into alignment and then treating it with iodine. The other, developed by Land and H. G. Rogers to meet the special high-temperature conditions imposed by the proposed Polaroid headlight system, gets its properties from the treatment of the stretched polyvinyl alcohol film by dehydration. Both are efficient polarizers for visible light, but give no indication of polarizing properties for the longer wavelengths. Nevertheless, Blake created his new polarizer simply by combining the two treatments, first treating the polyvinyl alcohol plastic with iodine and then dehydrating it.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

RUGGED ELECTRON TUBES

Rugged electron tubes are indispensable wherever electronic equipment is under severe conditions of vibration, shock or acceleration. Important in the development of such tubes are methods of testing for sturdiness and durability, because tube design depends on analysis of the ways in which ordinary tubes fail in service or under test. All aspects of tube ruggedization are included in a comprehensive program under way in the National Bureau of Standards' Electron Tube Laboratory.

A detailed knowledge of operating conditions and tube failures is a useful guide to the design of tubes that will be strong enough to operate properly under severe mechanical conditions. One phase of the project therefore consists of a survey of the actual operating conditions for electron tubes in various kinds of commercial, industrial, and military applications. This study provides a practical basis for the design of test equipment to simulate the hazards of actual use. The Bureau's facilities for testing the ruggedness of electron tubes now include vibration apparatus, mechanical resonance testers, high-impact shock machines, and high-speed centrifuges, so that almost any destructive field condition can be reproduced.

After receiving the various ruggedness tests, tubes are examined for structural failures. X-rays are frequently used to reveal the extent of structural changes without opening the tube envelope. Materials for certain tube elements are examined spectroscopically to determine their exact composition and to find impurities that might weaken the tube structure. Out of these studies come recommended specifications for materials best suited to particular applications. In some cases new materials and new methods of fabrication must be developed to meet unusual requirements of ruggedization.

In a sense, the creation of a rugged tube is brought about through a series of successive approximations. Its development might begin by applying appropriate mechanical tests to an existing commercial type whose electrical characteristics suit the intended application. The results would show in what way this tube type fails to meet the ruggedness requirements. A preliminary revision of the tube design could then be made with the test results as a guide, and a handmade tube constructed in the model shop. The same tests could then be repeated for this experimental model. The designer would probably then have

* Communicated by the Director.

a clear idea of the direction to take in order to achieve a satisfactory rugged tube. It might involve a search for better materials for use in some tube elements, new methods of fabrication, or better geometrical configurations and alignment of tube elements for maximum rigidity. The influence of each structural element on the over-all strength of the tube would be carefully considered. Thus, through a succession of several trial designs a suitable rugged tube would be evolved.

At present the cost of rugged tubes is about three or four times more than conventional tubes. However, as more is learned about production methods and materials applicable to rugged tube types, the cost should be considerably reduced, and it is likely that all preferred tube types will eventually be available in ruggedized form.

EXPERIMENTAL STONE MASONRY WALL

An experimental masonry wall faced with over 2000 specimens of stone from 47 states and 16 foreign countries has recently been erected on the grounds of the National Bureau of Standards. It will be used to study all phases of the weathering process on numerous varieties of stone as an aid in developing more reliable laboratory methods for predicting durability. The complete investigation will doubtless require many years, but some parts of the study will yield results in a comparatively short time. The wall is a cooperative project carried out jointly by the Bureau and the American Society for Testing Materials. Several other organizations, including producers of stone, have also cooperated.

The wall was designed so that a number of problems connected with the weathering of building stone could be studied in the one structure. These include permanence of color, discoloration, effects of combining different types of stone, waterproofing, durability, and dimensional stability. Special construction features were incorporated to facilitate the study of these properties.

A chart shows the location of each individual stone, and a catalog has been prepared which describes each sample by source, type, color, and texture. In all, these are 30 distinct types of stones, some of which are not commonly used as building stone. Many represent types which are of interest only in a local sense. A few of the lightweight materials like "tufa stone" and "coquina" may find wider usage if they prove to have suitable resistance in a more severe climate than that of the dry or mild regions where they have been used.

HEATER COMPENSATION IMPROVES STABILIZED POWER SUPPLIES

A new method of compensating for line-voltage changes in stabilized direct-current power supplies has been developed by the National

Bureau of Standards. In the new circuit arrangement, the heater-voltage fluctuations are used to compensate for the line-voltage fluctuations, thereby increasing the stability of the output voltage. This method can be applied to power supplies employing degenerative voltage stabilizers in which d-c. amplifiers compare the output voltage against a fixed reference voltage. When the output voltage changes, the resulting voltage difference between the output and the reference potential is amplified so that the resistance of a control tube restores the output voltage to its original value. Although stability of such power supplies without heater compensation is adequate for many purposes, heater compensation can be used to good advantage in power supplies for such constant-current devices as direct-current amplifiers and microwave oscillators.

In order to analyze the effect of heater compensation, measurements were made on a typical stabilized power supply (350 volts, $\frac{1}{4}$ ampere). The experimental heater-compensated power supply constructed at the National Bureau of Standards employs a type 6SJ7 pentode as the amplifier although other tubes of the same general type have been used with satisfactory results. Small portable dry batteries are used as a reference voltage. The control function is performed by several 6L6's connected in parallel. Six tubes can carry a load current of 250 milliamperes and present an internal impedance of only 2 ohms. The output voltage was found to be influenced by small changes in the heater voltage of the amplifier tube, but independent of the heater voltage of the control tubes. The correct screen voltage for maximum stability must be determined experimentally.

For a constant heater voltage, an increase in line voltage of ten volts results in an increase in output voltage of about 0.1 volt. With the high-voltage and heater transformers connected to a common line voltage and the screen grid voltage of the amplifier tube set at its proper value, the heater-compensated power supply shows a maximum deviation of 0.01 volt from the nominal 350-volt output for a ten-volt change in the input. This is a variation of less than 0.0005 per cent in output voltage for a 1 per cent change in the line. The extremes in line voltage were taken as 100 and 120 volts.

Heater compensation gives much better operation in most power supplies using degenerative voltage stabilizers, without sacrifice of design simplicity. The principles of heater compensation can also be applied to good advantage in both a-c. and d-c. amplifiers.

THE FRANKLIN INSTITUTE

MINUTES OF STATED MEETING

Wednesday, December 21, 1949

The Stated Monthly Meeting of The Franklin Institute was held on December 21, 1949, in the Institute's Lecture Hall. Mr. Richard T. Nalle, President, presided and called the meeting to order at 8:15 P.M. There were approximately 250 present to hear the speaker of the evening.

A short business meeting was held prior to the Lecture, the President stating that the minutes of the monthly meeting for November had been printed in full in the December issue of the JOURNAL OF THE FRANKLIN INSTITUTE and that, if there were no dissent, they would stand approved as printed. There was no contrary motion. The President called on the Assistant Secretary, Mr. Hamilton V. Bail, who read the Secretary's report in his absence.

The Assistant Secretary reported that Article IV, Section 5 of the By-Laws provided: "Nominations for Managers shall be made in writing at the Stated Meeting in the month of December. Each nomination paper must be signed by at least two members, who shall certify that the candidate will serve if elected." He read the names of the following gentlemen whose nominations had been made in conformance with these By-Law provisions:

E. Paul du Pont
Walton Forstall
Clarence L. Jordan
Ralph Kelly
Lionel F. Levy
Charles Penrose
James H. Robins
Philip H. Ward

No other nominations were presented, and the nominations were declared closed.

The members elected for the month of November were reported as:

Sustaining	1
Active	54
Associate	28
Student	12

The total membership as of November 30 was stated to be 5412.

A few announcements were made, including statements that the Annual Christmas Planetarium showing of the Star of Bethlehem would be continued through December until January 2; and that the Christmas Week Lectures for Young People under the James Mapes Dodge Foundation would be held at 4:00 P.M. on December 29 and 30 in the Lecture Hall of The Franklin Institute. Mr. Laurence F. Livingston of the du Pont Company will be the lecturer and will speak on "Progress in Better Living." These lectures are free and the public is invited to hear them.

President Nalle then reminded the members that in 1848 Elliott Cresson had deeded to two Trustees a fund from the income of which medals were to be prepared for presentation to The Institute and for award as The Institute should determine. He stated that the Deed of Gift further provided that successor Trustees to the original two named in the Deed should be elected by the membership of the Institute, that there were vacancies in these two trusteeships, and that it would be in order to elect two new ones at this meeting. He then suggested the election of Dr. Henry B. Allen, Executive Vice President of The Institute, and of Dr. John Frazer,

Secretary of the Committee on Science and the Arts, as continuing Trustees of the Elliott Cresson Medal Fund. Nominations were then made and seconded to that effect, and the two nominees were elected Trustees of the Fund by the members present.

Mr. Nalle then presented Dr. J. O. Perrine, Assistant Vice President of the American Telephone and Telegraph Company, New York, who spoke on "Multiple-voice Superhighways by Carrier Waves." Dr. Perrine's demonstration-lecture was concerned with recent developments in carrier current systems whereby many telephone calls could be sent simultaneously over a wire or a radio channel. Television channels over coaxial and microwave systems were discussed. There was an imposing array of functioning equipment with a number of acoustic and visual effects to show what is taking place electrically within the carrier system.

The meeting was adjourned with a rising vote of thanks to the speaker of the evening.

HAMILTON V. BAIL,
Assistant Secretary.

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS, DECEMBER 21, 1949

ACTIVE FAMILY

Thornton D. Hooper
S. Leon Israel, M.D.
Manuel M. Pearson, M.D.
Beryl Price
James A. Quaid
Arnold T. Sigler
William E. Simkin
Sydney S. Stern
Earl D. Sticklen
M. L. Thompson

ACTIVE

Norbert J. Armstrong, Jr.
Karl P. Billner
Thomas Blackadder, D.Sc.
Alfred Blasband
William A. Bodenschatz
Edward G. Boyer
Albert S. Carter, Ph.D.
Eugene H. Davis
Frederick B. Downing
William Frank Elias, Ph.D.
Lawrence J. Fuller
John M. Gluch
Charles S. Hicks
Paul M. Hummer
Alan T. Knight
Armin Kupperstein, D.D.S.
Louis G. McAfoos, Jr., M.D.
Harold S. McCurdy
Thomas F. McGowan
James B. Mehorter
William Meyer
Russell L. Moore
Harry L. Nancarrow
William H. Oldach
Robert Platt
Seth Pope
Edgar G. Porter
George Purnell
Swanie S. Rossander, Ph.D.
Gene Rove
Merle S. Schaff
Edward A. Snader
S. F. Spencer
J. George Teplick, M.D.
Irven Travis
William N. Weikel
Leo Weinrott
Alexander G. Wilson, Jr.

ACTIVE NON-RESIDENT

Frederick Molter Bender

NECROLOGY

Philip Barlement '43
A. W. K. Billings '13
Mrs. Edgar H. Butler '34
H. K. Carey, M.D. '44
R. L. Ettenger '17
Bernard M. Fine '42
Henry H. Fleisher '36
Paul A. Fusselman '42
Miss Cornelia Greenough '36
W. J. Humphreys, Ph.D., D.Sc. '21
Mrs. Amy L. Hutchinson '30
Frank B. Jewett, Ph.D., LL.D. '36
Robert Marshall, M.D. '49

MUSEUM

A child's genius for making things usually meets with parental approval, but it is a tenable supposition that Mrs. Chambers had to keep her Quaker temper under severe restraint when she discovered that her sixteen-year old son, Cyrus, had borrowed two solid silver teaspoons to build a model steam engine. When one looks at the tiny little model now displayed in the Museum one can only marvel at the exquisite workmanship. The whole thing—boiler, stack, engine, and base plate—weighs only nine pennyweights and ten grains, or rather less than half an ounce. The cylinder is one-sixteenth inch in bore and three-sixteenths stroke. It will run at a speed of 3000 r.p.m.

This little wonder of delicate skill, probably the smallest steam engine in the world, arouses no small admiration in the visitors, but the sight of it in operation frequently provokes the question: "Did the boy do anything worth while?" Apparently there is a deep rooted suspicion of infant prodigies, but it is baseless where Cyrus Chambers is concerned.

Born in 1833, at Kennet Square, Chester County, young Chambers was the son of a well established Quaker family. An indifferent scholar, he always displayed a flair for mechanics. Having followed Eli Whitney's example of experimenting with the family's watches and clocks, he made models of a paddle boat and a threshing machine (which would "thresh" one grain of wheat). His first practical achievement was the invention, in 1855, of a machine for folding paper. Horace Greeley had told him that paper could not be folded for books by machinery. Chambers accepted this statement as a challenge, went home and invented a suitable machine in which serrated blades tucked the sheets between knurled rollers with tapes to carry the once folded sheets from the first-fold rollers to the second, the second-folded to the third. This machine was marketed in 1856–57 and the company he founded is still producing paper folding machinery.

At the outbreak of the Civil War the company had to abandon its normal operation to engage in war work, and Chambers occupied himself with making sword and bayonet scabbards. Meanwhile he was thinking about another invention.

This was an augur brick making machine with an automatic cutter synchronized to the speed of the moving bar of clay. The first of these machines went into operation about 1868 at Fish House, New Jersey, and Chambers entered upon an affluent future. If any man is entitled to a statue in Chicago it is Cyrus Chambers. After the great fire had destroyed the major portion of that city, the Chambers high speed brickmaking machine was employed in the task of rebuilding. Beginning with a speed of about 25,000 bricks an hour, its production was accelerated to 40,000 to meet the needs of the emergency. There is probably no comparable illustration of the walls of an entire city being built from the product of a single man's machine.

Some seventy-five of Chambers' patents can be traced. None of them could parallel the two cited above, which were basic. But this versatile inventor never lost his interest in mechanical development. He was taken to witness the flight of the first airplane which flew between New York and Philadelphia. He was then almost totally blind but, when those who accompanied him described the descent and ascent of the airplane he was convinced that this was not the proper way for an airplane to be operated. It should fly straight up from the ground, he declared. Promptly, he set about acquiring the knowledge required to enable him to design an engine that would do what the helicopter now does, but at his death in 1911 he had not succeeded in obtaining a practical result.

Mothers are still recommended to count their spoons carefully, but an indulgent eye might be turned upon any loss if the thief is going to put them to such good use as Cyrus Chambers did with those of his mother.

THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

***Abstract of* Rotor Balancing with an Electronic Capacitor Gauge.**[1]—HOWARD D. WARSHAW.[2] Dynamic balancing machines have been developed which are capable of indicating

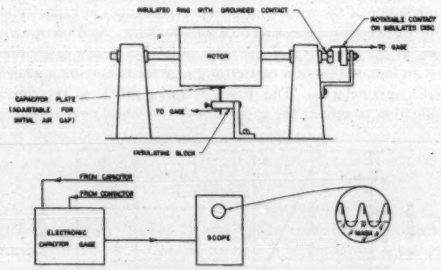

FIG. 1. Block diagram of complete system.

the magnitude and phase of unbalance of rotating parts, and these machines are indicated whenever production balancing is required. The field man is often called upon to balance rotating machines in place. In other cases, commercially available machines cannot be employed because the rotors are vertically mounted on step bearings or because of other special

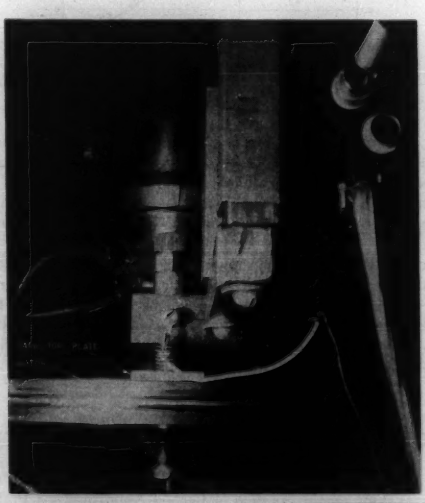

FIG. 2. Capacitor gauge installation.

[1] This paper is based on work done for the office, Chief of Ordnance, Department of the Army. Published in *The Review of Scientific Instruments*, Vol. 20, No. 7, 474–476, July, 1949.

[2] Research Engineer, The Franklin Institute Laboratories for Research and Development, Philadelphia 3, Pa.

construction. This paper describes a technique whereby electronic equipment which is portable and is easily employed in the field can be adapted to specialized balancing problems.

The measuring element of the gauge is a stationary capacitor plate mounted near the periphery of the rotor to be balanced, so that the plate and rotor form an electrical condenser. Changes in air gap produce changes in capacity (C) of the condenser in accordance with the formula $C = KA/d$, where K = a constant, A = area of plate, and d = thickness of air gap. During rotation, unbalance of the rotor produces cyclic changes in capacity that modulate the gauge circuit output displayed on the screen of a cathode-ray oscilloscope as shown in Fig. 1. Cyclic displacements at the periphery of the rotor of 0.0005 in. are easily detected.

Figure 2 shows an installation of a capacitor gauge for balancing a wheel that is to rotate at high speed about a vertical axis. Due to an irregular profile at the rim, it was more convenient in this application to mount the gauge above the wheel near its rim, as shown.

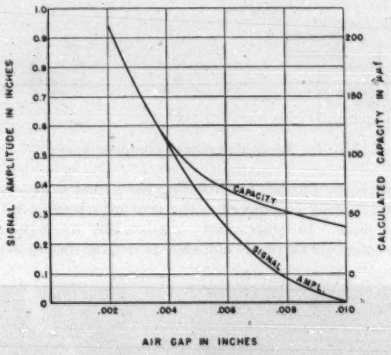

FIG. 3. Calibration curves.

The capacitor plate consists of a brass block (approximately 2 in. × 1 in.) supported on a threaded post that passes through a block of insulating material. This assembly is designed to permit adjustment of the plate for parallelism with the upper surface of the wheel, and to allow accurate setting of the initial air gap. The shaft contactor (not shown) is similar to that of Fig. 1 except that the rotatable contact is positioned by an electric motor drive controlled from a remote station.

The curve of capacity *versus* air gap, shown in Fig. 3, is based on calculated values for the capacitor installation of Fig. 2. With a linear electronic measuring circuit, the over-all sensitivity for air gaps greater than 0.004 in. would be relatively low. However, since the measuring circuit is not linear, the over-all calibration curve of signal amplitude *versus* air gap, as shown in Fig. 3, is obtained. The sensitivity at the wider air gaps is sufficient to allow this electronic capacitor gauge to indicate clearly rotor displacements covering a maximum range from zero to 0.008 in.

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL within the next few months:

FANO, ROBERT M.: A Note on the Solution of Certain Approximation Problems in Network Synthesis.

STONE, EARL E.: Communications and Electronics—The Most Essential Tools of Joint Command.

BOYAJIAN, A.: Origin and Meaning of Circular and Hyperbolic Functions in Electrical Engineering.
OUGHTON, CHARLES D.: Xeroprinting.
ROOP, WENDELL P.: The Part of Octahedral Theory in the Study of the Plasticity of Metals.
LEITNER, A. AND R. D. SPENCE: The Oblate Spheroidal Wave Functions.
SILBERSTEIN, LUDVIG: Developable and Developed Silver Halide Grains.
SUSSKIND, CHARLES: Henry Cavendish, Electrician.
MICHAELSON, HERBERT B.: Variations of Grid Contact Potential and Associated Grid Currents.
FO-VAN CHANG: Trigonometric Series Applied to the Bending of Long Rectangular Plates to a Cylindrical Surface.
HERSHBERGER, W. D. AND L. E. NORTON: Servo Theory Applied to Frequency Stabilization with Spectral Lines.

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BARTOL RESEARCH FOUNDATION

The Low Energy Spectrum of the Primary Cosmic Radiation, and the Magnetic Field of the Sun, by M. A. POMERANTZ. The results of the recently completed comparison of the primary cosmic-ray intensity at Fort Churchill, Manitoba (geomagnetic latitude 69°N) and Swarthmore, Pennsylvania (geomagnetic latitude 52°N) have led to the following conclusions, among others:

1. The heretofore assumed magnetic field of the sun does not impose a cut-off at the low energy end of the primary spectrum, as has previously been supposed.
2. The solar dipole-moment, if one exists at all, cannot exceed one-twentieth of the value previously accepted on the basis of rather controversial astrophysical evidence.
3. The differential energy spectrum of the primary cosmic radiation does not follow the inverse cube power law in the low energy region, as formerly believed.

Short Time Studies in Self-Quenching Geiger-Mueller Counters, by W. E. RAMSEY. Three investigations have been made involving mechanisms which operate in counters immediately following the initiation of the discharge.

The first concerns the current time relationship during the period when the discharge is spreading down the wire. So far, the current has been found essentially constant during this period if the spreading starts from a single point. If a number of electrons, freed by an ionizing ray, arrive simultaneously at the wire, several spreading centers are formed. In this case the observations suggest that until overlapping occurs, the current is proportional to the number of such electrons. Multiple centers would obviously reduce the spreading time and this is observed.

It has been shown that a simple two-tube electronic arrangement can be made to count the number of spreading centers. A counter operated with this circuit is directional for ionizing particles and will discriminate between particles of different specific ionization.

By terminating the spreading process, it is possible to confine the discharge to small segments of the wire. Ninety-five per cent of the volume of a 20-cm. tube was restored to sensitivity 5×10^{-7} seconds after the discharge was initiated at a point. This procedure has obvious use in high speed counting and also renders the instrument directional.

Linear Electron Accelerator, by B. L. MILLER. A resonant cavity accelerator, using three cavities—one for electron bunching and two for multiple acceleration—has produced 0.7 Mev electrons. A new model, using four accelerating cavities, is under construction and is designed to produce 1.5 Mev electrons by means of an HK7 10-cm. magnetron as power source. A convenient method, which does not require a known and uniform magnetic field for measuring the energy of the beam, is in use. Air core coils deflect the 10,000-volt injection beam and later the accelerated beam by the same amount; the ratio of the currents in the coils in the two cases is the momentum ratio for the electrons.

Activation Phenomena with Thoria Cathodes,[1] by O. A. WEINREICH. Three conditions of activation of thoria-coated tungsten cathodes are distinguished and their behavior and properties discussed. The first state is that of a freshly prepared cathode not previously heated above 1200° C. In this condition, the emission is very low and the work function is about 4.3 volts. The second state is that which is obtained by heating the cathode up to about 1700° C. This gives rise to values of thermionic emission which are of practical importance and which have good stability. The third state is formed by flashing of the material to 2600° C., and gives rise to very high values of emission. This state, however, is unstable, the emission

[1] As yet unpublished. To appear as a Letter to the Editor in the *Journal of Applied Physics*.

being rapidly poisoned by oxygen at 10^{-6} mm. Hg. It decays rapidly with normal emission and it is sensitive to the anode material. In addition to being produced by flashing, this state of high activation can also be created by ion bombardment, by reverse electron current, and/or by exposure to evaporation products from a nearby operating thoria cathode.

Some Characteristics of the 11-Day Neodymium, by C. E. MANDEVILLE. The 11-day activity of Nd^{147} was induced in pure Nd_2O_3 irradiated by slow neutrons in the Oak Ridge pile. Two beta ray groups, having end points at 0.17 Mev and 0.78 Mev, were resolved by aluminum absorption, and a lead absorption curve of the quantum radiations showed that two gamma rays are present, having energies of 35 Kev and 0.58 Mev. The soft gamma ray is about fourteen times more intense than the harder one at 0.58 Mev. The beta-gamma coincidence rate of Nd^{147} was observed to decrease from an extrapolated value of 0.21×10^{-3} coincidence per beta ray at zero absorber thickness to 0.12×10^{-3} coincidence per beta ray at an aluminum absorber thickness of 25 mg./cm.^{2}, and remain constant thereafter. This shows that both beta ray groups are coupled with gamma radiation. No beta-beta coincidences were observed in the decay of Nd^{147}.

***Abstract of* Lack of Depolymerase Effect on Desoxyribonucleic Acid in Living Cells.**—J. O. ELY AND M. H. ROSS (*Science*, 109: 367, April 8, 1949). Desoxyribonucleic acid depolymerase had been reported by several investigators to remove the ultraviolet light absorbing constituents and the Feulgen stainable material from nuclei in sections of tissue and from the nuclei of dead cells. There had been no reference, so far as these authors are aware, of the use of this enzyme on living cells.

Desoxyribonucleic acid depolymerase did not act on the nuclei of living chicken erythrocytes or of living cells of the Walker Carcinoma No. 256 of the rat; the enzyme acted on these cells after they were killed. Lack of effect of the enzyme on living cells apparently was not because of adsorption of the enzyme or antienzyme activity, but may have been because of cell membrane impermeability or inability of the enzyme to attack nucleic acid in the state that it exists in the living cell.

***Abstract of* Effects of Repeated Low Doses of Neutrons on the Estrous Cycle of the White Rat.**—JAMES L. LEITCH, DOUGLAS M. GAY, AND GEORGE A. NEVILLE (*Am. J. Roentgenol. Radium Therapy*, 61: 530, 1949). Neutron bombardment of twenty-three rats at the rate of 3 n daily for thirty-seven exposures caused a disruption of the estrous cycle as indicated by vaginal smears, a retardation of growth and temporary reduction in white blood cells in the circulating blood.

Swellings appeared in the mammary region of four rats uncorrelated with estrous cycle variations.

***Abstract of* Nucleic Acid and the Feulgen Reaction.**—J. O. ELY AND M. H. ROSS (*Anat. Record*, 104: 103, 1949). Hydrolysis of sections of tissue as carried out in the Feulgen technic was found to remove both ribonucleic acid and desoxyribonucleic acid from cells. Ribonucleic acid was removed rapidly, desoxyribonucleic acid more slowly.

Feulgen hydrolysis was found to depolymerize desoxyribonucleic acid, and remove purines; the unremoved polytetranucleotides of thymic acid which contain the aldehyde groups, in part, remain attached to the protein of the cells and in part become detached and diffuse into the hydrolyzate.

The Feulgen nucleal reaction was found to be specific for desoxyribonucleic acid in the sense that color is produced by combination of hydrolysis products of the nucleic acid with the Feulgen reagent. The technic is considered satisfactory for qualitative work but quantitatively there is loss of Feulgen reacting substance from the cell.

It was found that Feulgen's reagent could be kept for longer periods of time when containers were full and sealed and kept cold than when kept in partially filled unsealed containers.

Loss of an Associate Editor.—WILLIAM JACKSON HUMPHREYS, an associate editor of the JOURNAL OF THE FRANKLIN INSTITUTE, physicist and world authority on meteorology, died in Washington, D. C. on November 10, 1949, aged 87. Many of his important contributions to meteorology first appeared in this JOURNAL during the years from 1913 to 1946, including his famous "Physics of the Air." As an authority on clouds and physics of the air, he was known and highly regarded by meteorologists throughout the world.

Dr. Humphreys attended public school at Gap Mills, Virginia (now West Virginia), high school at Pomeroy, Ohio, Washington and Lee University at Lexington, Virginia, (B.A., 1886 and C.E. 1888), University of Virginia, and Johns Hopkins University (P.H.D., 1897). He began teaching physics in 1889 and was on the Staff of the University of Virginia from 1897 to 1905. During these years he went on eclipse expeditions with the Naval Observatory; one of these expeditions took him to Sumatra.

In 1905 Dr. Humphreys became associated with the U. S. Weather Bureau, as director of the research observatory newly established at Mt. Weather, Virginia, on the crest of the Blue Ridge five miles from Bluemont. At that time meteorologists throughout the world, despairing of further success in solving the problems of weather forecasting from observations at the bottom of the atmosphere, were turning their attention to a study of the upper air, by kite and balloon, by observations from mountain stations, and by a more intensive study of clouds. In this work, Dr. Humphreys took a leading part. Already a frequent contributor of scientific articles in the field of physics, he soon became a prolific writer on meteorological subjects.

The first notable contribution of Dr. Humphreys in meteorology was his explanation of the isothermal condition of the stratosphere which had been one of the puzzling phenomena of the upper air. There followed numerous contributions to the physics of the air; he gave special attention to optical phenomena—lightning, halo, rainbow, etc.—and made an intensive study of the physics and classification of clouds. Although a meticulous writer on scientific subjects, he had an unusual ability to interest the layman and often his talks became first-page copy for the newspapers.

Dr. Humphreys was the author of a number of books and co-author of several others. "*Physics of the Air*" went through three editions—1920, 1928 and 1940; "*Weather Proverbs and Paradoxes*" two, 1923 and 1934; "*Fogs and Clouds*" two, 1926 and 1943; while "*Rain Making and Other Weather Vagaries*," "*Weather Rambles*" and "*Ways of the Weather*" had a single edition each. He also wrote an autobiography "*OF ME*," collaborated with W. A. Bentley in the publication of "*Snow Crystals*," and wrote parts or chapters of several other books.

He was President of the Washington Academy of Sciences, President of the Cosmos Club, President of the American Meteorological Society and held numerous other offices in these and other professional and scientific societies. Also from 1911–1934 he was a part-time Professor of meteorological physics at the George Washington University. On retirement from the Weather Bureau in 1935, after 30 years of service for the government, he was appointed collaborator and continued to work at his desk there until the time of his death, though with frequent extended absences after he passed the age of 80 years.

On January 11, 1908, he married Margaret Gertrude Antrim of an old and well known Virginia family, who survives him. They had no children.

Dr. Humphreys ranked with the dozen outstanding meteorologists of his time, and his passing will be noted with regret in every part of the world.

BOOK REVIEWS

THE PHILOSOPHY OF NATURE, by Moritz Schlick, translated by Amethe von Zeppelin. 136 pages, 14 × 22 cm. New York, The Philosophical Library, Inc., 1949. Price, $3.00.

The results of sensory perception and ordinary analytical measurements having become inadequate to the comprehension of modern physics, the physicist of today is driven to resort to philosophical methods. The work of Moritz Schlick, too little known in this country, serves as a sound introduction to the philosophical approach to the physical sciences.

This brilliant student of Max Planck was the successor to Ernst Mach and Ludwig Boltzmann in the chair of "Philosophy of the Inductive Sciences" at Vienna, and was author of the comprehensive *Allgemeine Erkenntnislehre*. His first course of lectures, in the winter of 1922–23, dealt with the philosophy of nature and so met the needs of the moment that his influence brought about a revival of philosophical activity in the University. As his disciples dispersed this influence was carried abroad. The "Vienna Circle" as these philosophical scientists came to be called, attracted a good deal of attention at the conference on methodology of the exact sciences which met at Prague in 1929, and as a result of its contacts with foreign scientists its influence expanded, until it became generally recognized that a philosophical treatment was necessary if the study of physical science was to prosper and progress.

Schlick's premature death in 1936 when his school of philosophy was meeting with general acceptance prevented a full recognition of his share in the pioneer work. The publication of this book, it is hoped, will lead to a revival of interest in his work. Schlick did not develop any new system of philosophy. The task of science, he maintained, is to obtain a knowledge of reality, and the achievements of scientists cannot be destroyed or altered by philosophy, but "the aim of philosophy is to interpret these achievements correctly and to expound their deepest meaning. This interpretation is the ultimate, as well as the highest scientific task, and will always remain so." His undogmatic yet scientific way of philosophizing demanded a solid foundation for every assertion.

The present volume contains the outline for a precise philosophy of physics within his definition. Since it is composed of Schlick's notes for his course of lectures in 1936 it makes no pretence at being an extended account of the author's views on the subject. It is compact with suggestive and provocative assertions, so that a thoughtful reader will derive benefit and pleasure from closing the gaps in the presentation of ideas.

The editors deserve praise for having appended some of Schlick's writings on the relation between biology and physics, a field of investigation which, we feel justified in saying, would have been greatly enriched by this gifted author had not a lunatic's bullet terminated his life before the full expanse of his mind had been revealed.

Nor should the work of the translator be overlooked. Philosophic works by German authors are not, as a rule, easy reading, but Amethe von Zeppelin has produced a smooth translation, deftly presenting a difficult subject in a manner which would have met with the original author's approval for its conciseness and precision.

T. C.

ELECTRONICS: EXPERIMENTAL TECHNIQUES, by W. C. Elmore and Matthew L. Sands. 417 pages, drawings and photographs, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1949. Price, $3.75.

The forthcoming National Nuclear Energy Series is similar to the M.I.T. Radiation Laboratory Series in that it is an extensive revelation of highly classified wartime research supported by public funds. One volume, "Electronics: Experimental Techniques," covers the electrical instrumentation that was used in the Manhattan Project and will be of interest to certain electronics and communications engineers. The reader finds at once that the subjects

treated are of far more widespread importance than their restricted use in the single field for which they were developed. This will be recognized when it is seen that the book contains descriptions of pulse amplifiers, counters, sweep circuits and timing circuits.

The book will be valuable as an engineering reference in any of the fields in which the types of circuitry mentioned above have a familiar ring. Owing to the extremely large number of complete equipment circuit diagrams one has the impression that this is a manual of circuits for counters, timers, etc. The values of circuit components are included in all cases, giving the book a very practical aspect.

For the circuit designer a large portion of the book is devoted to elementary arrangements of vacuum tubes to accomplish fundamental functions such as mixing, clamping, coincidence, scaling, triggering and many others. Because of its slightly unusual but extremely utilitarian makeup, the book is highly recommended to practicing engineers.

The mechanical composition of the book likewise deserves special mention, for it is printed on non-glare, abnormally white paper in large, clear, black characters by a lithoprint process. Economy is achieved, so that the volume can be distributed at a welcome low price for a technical book of this type.

C. W. HARGENS

WEBS IN THE WIND, by Winifred Duncan. 387 pages, illustrations, 20 × 26 cm. New York, The Ronald Press Company, 1949. Price, $4.50.

The amateur has a definite place in the sciences. In the case of the professional scientist, all too often his work has been carefully laid out and the channels followed are not only well defined but in most cases so deep that it is mentally impossible to hurdle them to go afield in his researches. On the other hand, the amateur can do exactly as he wishes with no program to follow, no deadline to meet and only the immediate interest of his work to tie him to his task. Being a "free agent" the amateur can bite off a tiny piece of a problem and completely masticate and digest it to the point where all the available information has been extracted.

"Webs in the Wind" is a book written professedly by an amateur but whose context would make a professional proud. Miss Duncan deliberately starts out to investigate and write about a creature—any creature—as an explorer on an exploration trip to some unknown country. She chooses a subject which, in this case, happens to be the ubiquitous spider. When she begins studying the habits of this creature she finds that its habits seem rather strange and when she consults the authorities on spiders she finds there is nothing in the literature to answer her questions. So, from the amateur ranks, the author immediately enters the ranks of the professional with a substantial and concrete addition to arachnological research.

Miss Duncan tries to solve many of the mysteries associated with spiders, such as the method by which spiders can attach their lines to distant objects, the so-called cannibalism on the part of the female spider, the inability of spiders to break off the silk without attaching it to some object, and finally, and most important, the mating of spiders. This last mentioned item is one which seems to have escaped the observations of most arachnologists, and in the book Miss Duncan describes the mating habits of several species. She also demolishes the supposition that spiders are blind for she describes the courtship of a female by three males and the rejection of two of them. Of course, there is still a possibility that the spiders may recognize familiar objects by a sense of smell, or perhaps by a supersonic means created by the male drumming the web with his abdomen, but until that is proven I will go along with Miss Duncan and believe that spiders have a definite and well defined sense of sight.

The manner in which the various spiders form their webs is most fascinating, and Miss Duncan points out the little known fact that if a spider drops her web-making momentarily she will return to exactly the spot where she left off. The spiders seem to have an inherent and well developed sense of geometry in the way the webs are spun and the patterns they follow. The mesh webs are complicated triangles, quadrangles, and sexagons. Spiders seem to have an instinct not only for plane geometry, but solid geometry as well.

Seeing the Black Widow spider through the eyes of Miss Duncan, the spider becomes a fascinating creature and surprisingly enough, the fear and repugnance generally associated

with these creatures disappears, though the reviewer will still let them severely alone at any and all times.

As a result of reading this book one is engulfed by a feeling that there is an obvious conflict of opinion among arachnologists. Perhaps it may not be a divergence of opinion but rather the fact that the habits of spiders vary so widely from specimen to specimen even in the same family, that conclusions drawn from the observations of few specimens are quite apt to be fallacious. For this reason a reasonable amount of caution must be exercised in accepting the findings of a single researcher. Perhaps in the future when more literature on the subject becomes available and a thorough integration of the work is available the behavior patterns of spiders may become known.

The book is one of the most pleasant and enjoyable books on nature study this reviewer has read in a long time. The drawings and figures are the author's own without the artist's interpretative strokes added. "Webs in the Wind" is heartily recommended for the reader.

I. M. LEVITT

PRINCIPLES AND PRACTICE IN ORGANIC CHEMISTRY, by Howard J. Lucas and David Pressman. 557 pages, diagrams, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1949. Price, $6.00.

This is primarily a laboratory text designed for students of organic chemistry. Its material and organization, however, will make it useful to other workers in organic chemistry. All the material prerequisite for good laboratory instruction is combined with much that is of general interest.

The first chapter of this text is devoted to an elementary discussion of the thermodynamics involved in organic reactions. The importance of the free energy change, and heat of reaction upon equilibria is emphasized along with the effect of concentration, temperature, solubility and catalysts. The student is encouraged to think of organic reactions with the purpose of controlling conditions, thereby obtaining better products and optimum yields. Tables of molal-reduction potentials, bond energies, free energies of compounds, and resonance energies are included to aid in the control and study of these reactions.

In the second chapter the importance of solvents for regulating reaction rates, controlling temperature and achieving homogeneous systems is discussed. This, together with the use of solvents in the purification and extraction of organic substances, justifies the adequate outline of various solubility relationships. A table of dielectric constants of the more common solvents is given.

Various operations, such as crystallization, determination of melting point, sublimation, distillation, drying, and extraction, so essential in the preparation of organic compounds, are thoroughly covered in the following sections.

The remainder and major part of the book is naturally given to the study of particular compounds and methods of preparation. Equations and the application of various principles to the types of reactions, rates and purification, are given together with directions for specific experiments. The number given is large enough to allow for choice in respect to difficulty and length of time involved. Different students can be assigned various experiments so that the class as a whole covers a larger territory.

Each chapter is supplemented with sets of notes and questions so that the worker thoroughly understands all the principles involved and acquires the ability to carry out difficult reactions from even meager directions. Two additional chapters on the special techniques of chromatography and qualitative organic analysis give additional value to a text that should prove very useful to all students of organic chemistry.

G. CATHERS

ACOUSTIC MEASUREMENTS, by Leo L. Beranek. 914 pages, 15 × 22 cm. New York, John Wiley & Sons, Inc., 1949. Price, $7.00.

Dr. Beranek, the wartime director of the Electro-Acoustic and Systems Research Laboratory at Harvard and at present Technical Director of the M.I.T. Acoustics Laboratory, has written a comprehensive source book for specialists and advanced students of acoustics in the

fields of physics, psychoacoustics, communications, otology, and industrial applications. A book of this nature has long been overdue mainly because practical problems in acoustics are such that an experimental approach is often the only feasible attack, but this is not to imply that theory has in any way been neglected by Dr. Beranek. It is a laudable achievement in itself that the influences of mathematical physics, electronic circuitry, and experimental psychology have been so skillfully merged in this volume without disproportionate emphasis on any one approach. Furthermore, the tremendous advances in the application of acoustics to previously unforeseen problems made during the last decade, in particular the research done under OSRD and ONR contracts, has not been available hitherto in such lucid and convenient form.

Perhaps the most effective way to review a book of the vast scope of "Acoustic Measurements" is to indicate the detail of coverage in a small section rather than to attempt to specify all of what has been covered. For example, in the section on types of sound-detecting equipment, the following information is presented: the human ear is discussed in sufficient detail to make evident to interested persons those phenomena which must be considered when a human is a functioning part of certain larger mechanisms, such as an airplane; mention is made of the effect whereby for a given sound pressure at the eardrum a tone appears 7 decibels louder in a free field than in an earphone, and of the masking effect for pure tones and for random noise; the section goes on to discuss in detail carbon, condenser, moving coil, ribbon, piezoelectric, and directional microphones without, however, attempting to arrive at a complete catalogue of types, but rather preferring to present an adequate survey. This small section ends with a discussion of devices for making measurements in moderate winds as well as in high winds such as might be encountered on a rapidly moving vehicle.

In conclusion it should be reiterated that Dr. Beranek has done an excellent job as well as a great service by writing a critical and detailed encyclopedia of acoustic measurement techniques.

EZRA S. KRENDEL

FUNDAMENTALS OF VACUUM TUBES, by Austin V. Eastman. Third edition, 644 pages, drawings and photographs, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1949. Price, $5.50.

Eastman's "Fundamentals of Vacuum Tubes" in its revised form is a logical selection for inclusion in the new Electrical and Electronic Engineering Series which the McGraw-Hill Co. is publishing. This is true for two reasons. First, the series covers such a large field and includes so many highly specialized volumes that one book of a more general, introductory nature is required. Although this book has not been so designated, it fills the above requirement extremely well since electronics engineering appears to be the main subject of the series if one judges by the books that have so far been included. (The others are: Hessler and Carey, "Fundamentals of Electrical Engineering"; Hill, "Electronics in Engineering"; Seeley, "Electron Tube Circuits"; Spangenberg, "Vacuum Tubes"; Terman, "Radio Engineering.")

The second reason for acknowledging the place of Eastman's new edition in the series is its coverage of recent literature. For example, the author has picked up all the significant articles written recently on cathode follower operation. In general, most of the literature through 1947 has been screened for fundamental contributions, and these have been included, not merely as footnotes but as modifications or extensions of standard derivations in the text.

The Electrical and Electronic Engineering Series as a whole is herewith recommended for the reference shelf. "Fundamentals of Vacuum Tubes" is suggested as an introduction to Spangenberg's "Vacuum Tubes."

C. W. HARGENS

THE CRYSTALLINE STATE, by Sir Lawrence Bragg. 352 pages, photographs and diagrams, 14 × 22 cm. London, G. Bell and Sons Ltd., 1949. Price, $8.50.

This book is essentially a reprinting of an earlier volume, published in 1933. It was originally intended as the first of a series of three volumes, and was to provide a general intro-

duction to the subject of crystallography. The second and third volumes, which are only now nearing completion, were to give a more detailed treatment of specific subjects in the theory and techniques of X-ray analysis, and in the interpretation of these analyses from the standpoint of crystal physics and chemistry.

This volume contains a quite complete but not unduly detailed survey of the subject of crystallography. The survey includes a discussion, with examples, of the experimental methods used in crystal analysis; the general fundamentals of diffraction from crystal lattices; the elements of the geometry of crystal symmetry systems, crystal classes, and space groups; the physical chemistry of crystals; and the physics of X-ray and electron diffraction. An historical survey is included, but is reserved for a late chapter. In the appendices are given more detailed information about the production and properties of X-rays, and tables of emission spectra and absorption edges, absorption coefficients, atomic scattering factors, and space group nomenclature. A short bibliography of reference books, which has been brought up to date, is included.

The survey nature of the book should make it a valuable text and general reference for the worker in other fields who wishes to be familiar with the methods and language of crystallography. A very clear descriptive style and copious use of simple diagrams greatly increase its value as a reference text. The material included in the physical chemistry section is now out of date, but still serves to illustrate the methods used in and the types of information available through X-ray studies.

A. D. FRANKLIN

BOOK NOTES

MODERN OSCILLOSCOPES AND THEIR USES, by Jacob H. Ruiter, Jr. 326 pages, illustrations, 15 × 24 cm. New York, Murray Hill Books, Inc., 1949. Price, $6.00.

The author, who is associated with the Allen B. DuMont Laboratories, Inc., has prepared a comprehensive work covering all phases of the oscilloscope. His treatment is designed for those who have little acquaintance with the subject but to whom a thorough understanding would be helpful. For these readers, electronic students and radio technicians and repairmen with a background of general physics, emphasis has been placed on the learn-by-doing method of instruction and many step-by-step procedures are given throughout the volume.

In his introductory chapters the author defines the oscilloscope as "an instrument which may be used to observe and measure any vibration or oscillation that can be converted into an electrical voltage." A brief discussion is given of various types of mechanical oscillographs Three chapters are devoted to a consideration of the principles and construction of the cathode ray tube which forms the basis of the oscilloscope. After a description of a general purpose oscilloscope and a discussion of the various circuits necessary to its operation, the techniques to be employed in its handling are detailed. A useful feature of this chapter should be the table comparing the names given the different controls on the panels of various models.

The interpretation of the patterns shown on the screen is fundamental and the basic patterns are well illustrated. The use of the oscilloscope in servicing both AM and FM radio receivers and television receivers is fully described. Other applications are noted and an interesting chapter considers possible uses of the oscilloscope as a visual aid in teaching such subjects as sound, electricity and electronics. A concluding chapter discusses the technique of photographing cathode ray patterns. Among the features are a glossary and numerous illustrations. This is a practical and useful book on a device which has assumed considerable importance in the field of electronics.

APPLIED MECHANICS, by Alfred P. Poorman. Fifth edition, 388 pages, diagrams, 14 × 21 cm. New York, McGraw-Hill Book Co., Inc., 1949. Price, $4.00.

A standard textbook for undergraduate courses in mechanics in engineering schools for thirty-two years, this work has again been revised. A change has been made in the location of

problems, which have also been numbered consecutively throughout the book to facilitate reference. Some new material has been added and other changes made as new practice requires.

INORGANIC PREPARATIONS, by H. F. Walton. 183 pages, illustrations, 14 × 21 cm. New York, Prentice-Hall, Inc., 1948. Price, $3.00.

This volume offers a selection of experiments in preparing inorganic preparations, designed to meet two goals—instruction in the common techniques and reactions of preparative inorganic chemistry, and familiarity with the appearance and properties of typical inorganic substances. Since the purpose of the work is educational rather than practical, the preparations have been chosen to illustrate particular points and have been arranged by type of compounds and type of reactions. Introductory chapters discuss briefly some of the pertinent background information. Tests and questions have also been included.

MECHANICAL ENGINEERING PRACTICE, by Charles F. Shoop and George L. Tuve. Fourth edition, 513 pages, illustrations, tables, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1949. Price, $4.50.

In revising this standard textbook and laboratory manual on experimental engineering, the authors have added new chapters on fuels and combustion, and automatic controls, as well as much new material in the fields of heating and air conditioning, refrigeration and internal-combustion engines. Various new types of equipment which have been developed since the previous edition are described, and in addition new tables and charts have been included to maintain its dual role of textbook and reference handbook.

FUNDAMENTAL ALGEBRA WITH PRACTICAL APPLICATIONS, by Robert L. Erickson. 317 pages, diagrams, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1949. Price, $2.80.

In preparing this text on algebra, the author has devoted considerable attention to the arithmetic necessary to study algebra. A wide variety of topics has been covered and in choosing examples an attempt has been made to appeal to the experiences of the student and to provide a practical application of the subject. Historical notes have been included and a large number of problems, but no answers, are given.

ELECTRICAL ENGINEERS' HANDBOOK, VOLUME 1. ELECTRIC POWER, edited by Harold Pender and William Del Mar. Fourth edition, v.p., illustrations, 16 × 21 cm. New York, John Wiley & Sons, Inc., 1949. Price, $8.50.

To keep this handbook abreast of the many recent developments in the field of electric power it has again been revised. Although some material has been omitted, such as section 19, *Electricity on the Farm*, replaced by *Rural Electrification Distribution Systems*, there have been many additions, resulting in a net gain of nearly four hundred pages. Similarly the number of contributors has increased from fifty to seventy-one, indicating the increased importance of various subjects. Among these may be noted electronic rectifiers, aircraft equipment, heat pumps, servomechanisms, and induction and dielectric heating apparatus. The bibliographies which have been an important feature of the work have been maintained.

Comprehensive in scope, this handbook maintains its position as a standard reference work in the field of electrical engineering.

THE TECHNIQUE OF RADIO DESIGN, by E. E. Zepler. Second edition, revised, 394 pages, diagrams, 14 × 21 cm. New York, John Wiley & Sons, Inc., 1949. Price, $5.00.

The general scope of this second edition follows closely that of the first. More attention has been paid to fundamentals although in the presentation of new material its practical application has been kept in mind. The chapter on receiver noise has been completely rewritten and throughout the book there have been added twenty-three diagrams.

CURRENT TOPICS

Cosmic Rays Explode Magnetic Sun Theory.—Cosmic ray detective work 20 miles high over northern Canada has exploded the widely accepted theory that the sun acts like a powerful magnet.

This notable scientific development was announced recently by the National Geographic Society as the outcome of a late summer research program conducted above the shores of Hudson Bay under sponsorship of the Society in collaboration with the Bartol Research Foundation of Swarthmore, Pa., and the Defense Research Board of Canada.

Data developed during the program are expected to open the way to wider knowledge of atomic physics, a field in which man's grasp is still limited despite all the attention the subject has received since the first successful release of atomic energy during World War II experiments.

Disproven Theory

The research project was under the direction of Dr. Martin A. Pomerantz of Bartol Foundation, who used the Canadian defense outpost of Fort Churchill as his operating base.

The theory he set out to test was that the sun possesses a permanent magnetic field, having a strength at its surface roughly 100 times that existing at the earth's surface and thus able to prevent any primary cosmic rays of low energy from ever reaching our globe. According to the old hypothesis, this solar field would operate to keep the intensity of the radiations at a constant level north of a particular geomagnetic latitude.

Dr. Pomerantz reports, however, that his Churchill experiments recorded cosmic radiations of such small penetrating power that they could not have entered the earth's atmospheric domain had a permanent solar magnetic field been operative to the extent long assumed by many scientists.

On the contrary, Dr. Pomerantz said, the expedition found no evidence to indicate that any observable permanent field exists. Even if the assumed solar field had only one-twentieth of the strength previously ascribed to it, he explains, the weak rays recorded by the expedition would have been held back.

(The activity of sun spots is accompanied by magnetic phenomena of widely varying intensities, but the magnetic fields set up by these sporadic outbursts are quite distinct from the concept of a permanent solar magnetic field which was under investigation.)

At Atmosphere's Edge

The research was carried out at altitudes varying from 100,000 to 110,000 feet, the zone representing the outermost one per cent of the earth's atmosphere. These observations can be made only at great heights because the relatively low-energy primary cosmic rays which must be detected undergo structural changes, and are absorbed before they penetrate very deeply into the earth's atmospheric envelope.

Free-balloon flights carried aloft a four-fold coincidence arrangement of Geiger counters for the work. Whenever a cosmic ray particle passed through the four counters in a certain direction, a signal was produced and relayed to a

mobile laboratory on the ground. Instruments also transmitted continuous information regarding atmospheric pressure and temperature inside the miniature gondolas carrying the scientific equipment.

Individual flights lasted from six to twelve hours. Although outside temperatures at the 20-mile altitudes averaged about 60 degrees below zero, Fahrenheit, a special arrangement within the gondolas maintained the apparatus practically at room temperature.

Wide Voltage Variance

Previous experimental programs have established that only cosmic rays of great energy can penetrate into equatorial regions where the earth's magnetic field is the strongest, and has the effect of deflecting intruding radiations. The lowest energy of cosmic rays arriving vertically at the equator is of the order of 14 billion volts.

As one moves north of the equator the deflecting interference of terrestrial magnetism decreases. At Philadelphia, for example, cosmic rays require an energy of only 2 billion volts to penetrate to the top of the atmosphere through the earth's magnetic barrier. This means a marked increase in the number of particles detected in a given time by a particular device, because in addition to the rays exceeding 14 billion volts there is a new group of particles having energies between 2 and 14 billion volts.

At Churchill, Dr. Pomerantz reports, rays of the relatively low energy of 100 million volts were reaching the top of the earth's atmosphere. This strength is in the range produced in some of the most powerful cyclotrons today, so that the data secured on the cosmic rays in the far north offer a basis for comparison with the mechanically produced radiations of physicists' laboratories.

Physicists believe that the results of the research by Dr. Pomerantz will enhance understanding of the nature and properties of high-energy charged particles (such as serve as the bombarding "bullets" in atom smashers), and of their interaction with matter.

A new altitude record for instrument-carrying free balloons was made in the course of rechecking cosmic ray readings over the Philadelphia area, for comparison work after the Fort Churchill expedition. Dr. Pomerantz on October 4 sent a team of instrument-carrying free balloons to 136,000 ft. The previous record was 128,000 ft., set in August, 1947.

An In-flight Refueling System to replace the British method now in use has been developed by Boeing for the Air Force. Major feature is a telescoping pipe "flying boom" near the tail of a B-29 tanker. Held directly aft when the tanker plane is grounded, the boom is "flown" to proper positioning on the nose of the plane being refueled, by means of small "ruddervators" similar to paravanes. The new boom is expected to overcome difficulties encountered with flexible tubing.

The World's Most Powerful Radio Station will be built by the Navy at Jim Creek, Washington, in the next 18 months. Developing more than 1,000,000 watts, the station will provide effective all-weather Naval communications in the area. Contractors' bids were opened in Seattle in November for the construction of a million-dollar transmitter building to be made of reinforced concrete in a modified T-shape.

Founder's Medal of Drexel Institute.—The Franklin Institute of the State of Pennsylvania was honored December 13, when the silver Founder's Medal of Drexel Institute of Technology was presented to it. Richard T. Nalle, president of The Franklin Institute, accepted the Medal which was presented by Dr. James Creese, president of Drexel, at a dinner in the Great Court of Drexel.

The citation, read by Dr. Creese, stated that the Medal was granted to The Franklin Institute, "because in the spirit of that practical scholar from whom it (The Franklin Institute) takes its name, this Institute, through one hundred and twenty-five years, has fostered public interest in the creative works of science and the mechanic arts; because it has made the city of Philadelphia a place of appraisal for scientific and industrial accomplishment everywhere and because for all the people in this industrial community . . . . it has made possible a more satisfactory understanding of the uses to which modern science can be put for the good of all."

Mr. Nalle, who accepted the Medal on behalf of the Franklin Institute's total achievement by its entire personnel, called attention to the close bond between Drexel and The Franklin Institute. In part he said, "There is, indeed, a great deal in common between Drexel and The Franklin Institute. You train and educate men and women in the field of science and the technical arts. Much of our own effort is directed toward awakening the first interest in sciences in the receptive minds of school children whose mental characteristics and preferences lie in this direction. It is very probable that many of your students over the years received their original impulse to become technical people from their visits to The Franklin Institute."

Leica Tandem Mount for Stereo and Color-Monochrome Duplication.—Adding still another chapter to the well-known story of Leica versatility, E. Leitz, Inc., announces its newest camera accessory, the LEICA TANDEM, designed to make possible both stereoscopic and simultaneous color and black and white photography.

Invented by Wim Berssenbrugge, internationally known Dutch specialist in color stereo photography, the TANDEM, in essence, is a coupling device which permits the use of *two* identical Leica cameras in perfect synchronization.

In stereoscopic applications, the TANDEM makes possible effective vertical three-dimensional depth through the Leitz "Stereoly-Polaroid" two projector system. However, it is believed that the greatest appeal of the TANDEM to the advanced Leica photographer is its ability to make identical color and monochrome shots.

The magazine photographer, for example, is often required to submit a selection of both types of photographs to the art editor in order to allow the most effective picture treatment possible within a given budget. The high cost of color reproduction often limits the number of color shots the editor may use to illustrate a story. And the black and white shots which are necessary for continuity are, of course, cheaper to reproduce. By providing identical shots in *both* color and black and white, use of the TANDEM eliminates the need for making monochrome negatives of selected shots if color *alone* was used.

One of the chief attractions of the TANDEM is its extreme flexibility. Since the shutter of the top Leica may be wound, set and released independently of the lower Leica, the photographer is not tied down to duplicating every exposure on black and white and color film. When duplicate shots are required, he winds both shutters with the TANDEM coupling knurl; for a single shot he winds only the top Leica.

Miniature Atomic "Explosion" in Billionth of a Second Can Be Observed by Use of New RCA Oscilloscope.—A storage oscilloscope, capable of "freezing" for a full minute electrical signals or traces which occur in a billionth of a second, was revealed by L. E. Flory and W. S. Pike, RCA Laboratories research engineers, at a meeting of the New York Section of the Institute of Radio Engineers in the Engineering Societies Building.

The device, based on the Graphechon—a tube with "visual memory" developed by RCA Laboratories—and the use of a television screen instead of the conventional oscilloscope, permits scientists to study and photograph instantaneous phenomena which previously had been impossible to see and most difficult to photograph, Mr. Flory said.

"The trace resulting from a miniature atomic 'explosion' may occur on the screen of an oscilloscope in a billionth of a second," Mr. Flory explained. "The human eye can't detect it for study and it can be photographed only on super-sensitive film.

"The storage oscilloscope can probe the secrets of other devices and processes, less dramatic than nuclear fission, perhaps, but of great importance to our everyday living. It can record and retain a trace indicating exactly what happens when a circuit breaker is opened and a current leaps across the gap, thus making possible the development of better breakers which will give the public better electric service."

The heart of the storage oscilloscope, which was developed by Mr. Flory and Mr. Pike with the assistance of J. E. Dilley and R. W. Smith, also of RCA Laboratories, Princeton, N. J., is the Graphechon memory tube.

This tube, Mr. Flory said, has a target on which an electrical charge, such as an oscilloscope or radar trace, can be "written" at any speed desired by an electron gun. The charge, or signal, is scanned or "read" off the reverse side of the target by an iconoscope-type electron beam such as is used in television. The beam may take as long as 60 seconds to remove the charge completely—thus providing the storage period. The signal is then amplified and applied to a kinescope, or television viewing screen, for inspection or photographing.